Volumetric and Sedimentation Survey of LAKE MARBLE FALLS

February 2020

Texas Water Development Board

July 2021

Texas Water Development Board

Prepared for:

Lower Colorado River Authority

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Published and distributed by the

Texas Water Development Board

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Executive summary

In May 2019, the Texas Water Development Board (TWDB) entered into an agreement with the Lower Colorado River Authority (LCRA) to perform a volumetric and sedimentation survey of Lake Marble Falls (Burnet County, Texas). Surveying was performed using a multi-frequency (208 kHz, 50 kHz, and 12 kHz), sub-bottom profiling depth sounder. Additional data were collected with a Trimble® R8-Model 4 Global Navigation Satellite System (GNSS) survey system to collect singular data points either by walking or wading. The GNSS system is a Real Time Kinematic with differential GPS (RTK-GPS) system that utilizes a base station with multiple rovers to collect data. Sediment core samples were collected in select locations and correlated with sub-bottom acoustic profiles to estimate sediment accumulation thicknesses and sedimentation rates.

Starcke Dam and Lake Marble Falls are located on the Colorado River in Burnet County, near Marble Falls, Texas. The target operating range of Lake Marble Falls is 736.20 to 737.00 feet above mean sea level. The top of the flood gates is at elevation 738.54 feet. The TWDB collected bathymetric data for Lake Marble Falls on February 12 and February 13, 2020, while daily average water surface elevations measured between 736.36 and 736.31 feet above mean sea level, respectively. Additional data were collected between Wirtz Dam and Granite Shoal on April 6, 2021, while the daily average water surface elevation measured 736.42 feet.

The 2020 TWDB volumetric survey indicates Lake Marble Falls has a total reservoir capacity of 8,568 acre-feet and encompasses 645 acres at top of flood gate elevation (738.54 feet above mean sea level). The 2020 TWDB volumetric survey indicates Lake Marble Falls has a total reservoir capacity of 7,597 and encompasses 613 acres at conservation pool elevation (737.00 feet above mean sea level). The accuracy of the TWDB survey was assessed using the root mean square error (RMSE) method. Between the axial profile points and the model surface, the RMSE equals 1.98 feet. The value 1.98 was added to and subtracted from the survey data and interpolated data points to find the range of uncertainty for the volumetric survey. Results at top of bathymetric model elevation 738.00 feet suggest the total reservoir capacity estimate is accurate to within ± 12.7 percent (± 1,042 acre-feet). The accuracy assessment highlights the difficulty in modeling the highly variable terrain of undulating, irregular sandy and gravelly bottom found throughout Lake Marble Falls.

Previous capacity estimates at elevation 738.00 feet include a 1964 Lower Colorado River Authority estimate of 8,760 acre-feet and a 2007 TWDB estimate of 7,795 acre-feet. Because of differences in past and present survey methodologies, direct comparison of volumetric surveys to others to estimate loss of area and capacity can be unreliable. The 2020 TWDB survey results do not mean the reservoir has gained capacity since 2007. Rather it is a result of data collected over a larger area and improved methods. Information from past surveys are presented here for informational purposes only.

The 2020 TWDB sedimentation survey measured 320 acre-feet of sediment. The sedimentation survey indicates sediment accumulation is greatest towards the dam. However, it is likely this is sediment that has been re-distributed throughout the reservoir and not post-impoundment sediment deposits. Post-impoundment sediment is negligible. The TWDB recommends a similar methodology be used to resurvey Lake Marble Falls in 10 years or after a major high flow event. Due to the irregular bottom, riverine behavior of the reservoir, and responses to high flow events, a multibeam survey should be considered to more accurately measure capacity and identify changes in the reservoir bottom.

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Note: References to brand names throughout this report do not imply endorsement by the Texas Water Development Board

Introduction

The Hydrographic Survey Program of the Texas Water Development Board (TWDB) was authorized by the 72nd Texas State Legislature in 1991. Texas Water Code Section 15.804 authorizes the TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In May 2019, the TWDB entered into an agreement with the Lower Colorado River Authority, to perform a volumetric and sedimentation survey of Lake Marble Falls (Texas Water Development Board, 2019). This report provides an overview of the survey methods, analysis techniques, and associated results. Also included are the following contract deliverables: (1) an elevation-area-capacity table of the reservoir acceptable to the Texas Commission on Environmental Quality (Appendices A and B), (2) a bottom contour map (Figure 6), (3) a shaded relief plot of the reservoir bottom (Figure 4), and (4) an estimate of sediment accumulation and location (Figure 9).

Lake Marble Falls general information

Starcke Dam and Lake Marble Falls are located on the Colorado River in Burnet County, near Marble Falls, Texas (Figure 1). Lake Marble Falls is owned and operated by the Lower Colorado River Authority (LCRA). Construction of the dam began on November 6, 1949, and the dam was completed in October 1951. Deliberate impoundment of water began in July 1951, and power generation started on September 25, 1951 (Texas Water Development Board, 1971). The reservoir was built primarily for hydroelectric power (Dowell, 1964; Lower Colorado River Authority, 2021). Additional pertinent data about Starcke Dam and Lake Marble Falls can be found in Table 1.

Water rights for Lake Marble Falls have been appropriated to the Lower Colorado River Authority through Certificate of Adjudication No. 14-5481. The complete permits are on file at the Texas Commission on Environmental Quality.

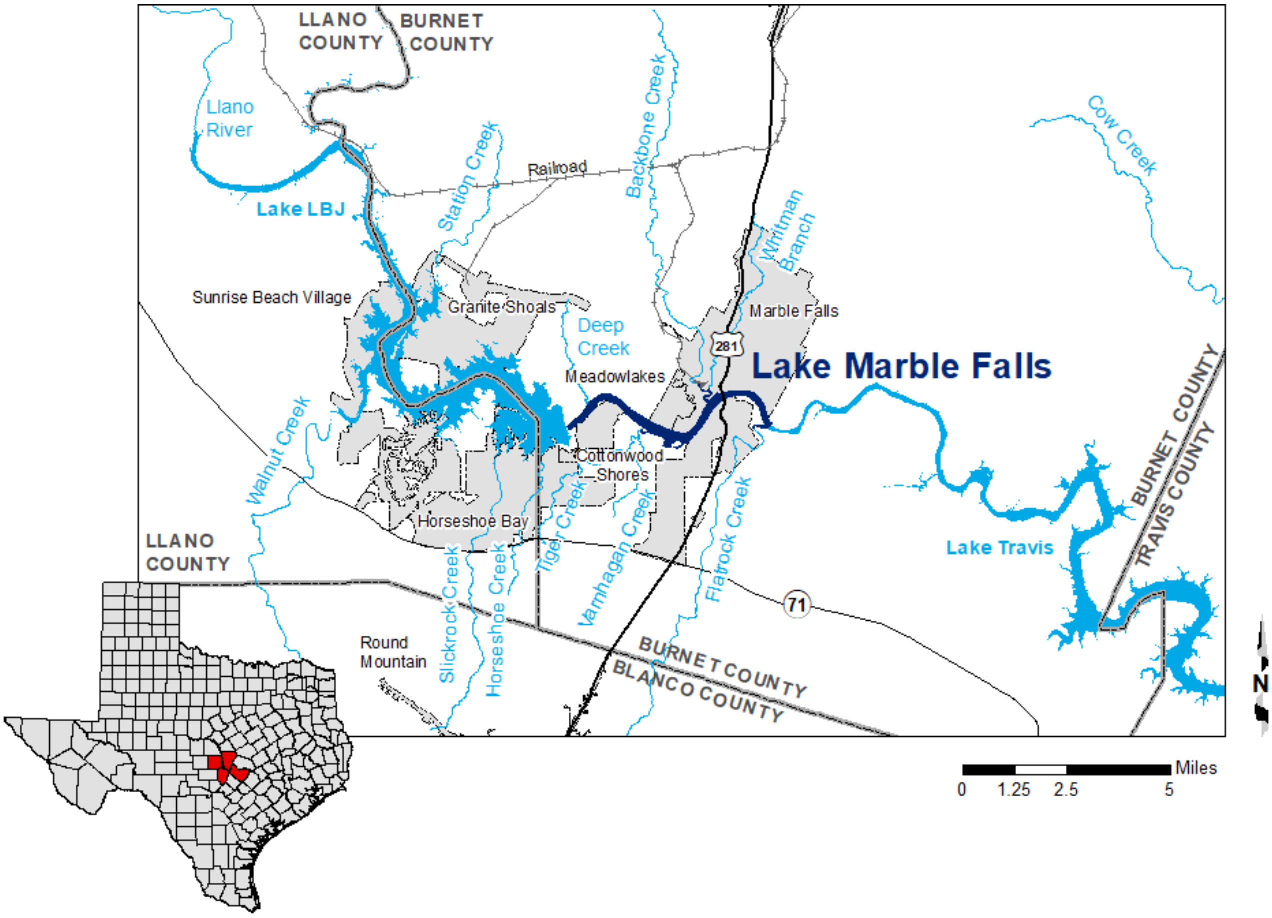


Figure 1. **Location map.**

Table 1. Pertinent Data for Starcke Dam and Lake Marble Falls

Owner(s)

Lower Colorado River Authority (LCRA)

Engineer (Design)

Fargo Engineering Company

Purpose

Hydroelectric power

Drainage Area

36,325 square miles of which 11,900 square miles are probably noncontributing. River flow is regulated by upstream reservoir storage and powerplant operation.

Dam

Type	Concrete with crest lift gates
Length	860 feet (includes powerhouse)
Top Width	13 feet
Base Width	56.83 feet
Maximum Height	98.8 feet to top of the control piers

Spillway

Type	Ogee section
Length (net)	608.3 feet
Crest Elevation	725.54 feet above mean sea level
Control	10 floodgates, each 60 feet wide by 15 feet tall
Discharge capacity	10 floodgates at 9,020 cubic feet per second each 1 turbine at 5,500 cubic feet per second 1 turbine at 5,200 cubic feet per second
Total discharge capacity	101,000 cubic feet per second

Outlet Works

No low-flow outlets required. Water releases are made through turbine operation.

Power Features

Two generating units with a total capacity of 41.4 megawatts.

Reservoir Data (Based on 2020 TWDB survey)

Feature	Elevation (feet above MSL)	Capacity (acre-feet)	Area (acres)
Top of dam	761.50	29,219	1,331
Top of flood gates	738.54	8,568	645
Top of conservation pool elevation	737.00	7,597	613

Source(s): D. Yates, written commun(s)., 2021, Lower Colorado River Authority, 2021; Texas Water Development Board, 1971; Texas Water Development Board, 2007.

Volumetric and sedimentation survey of Lake Marble Falls

Datum

The vertical datum used during this survey is feet above mean sea level. This is the legacy datum used by the LCRA. The legacy datum is based on elevation benchmarks set for construction of the dams forming the Highland Lakes that have not been adjusted to a standard datum (Lower Colorado River Authority, 2020). To convert to standard datum National Geodetic Vertical Datum 1929 (NGVD29), add 0.50 to LCRA Legacy Datum. To convert to standard datum North American Vertical Datum 1988 (NAVD88), add 0.69 to LCRA Legacy Datum. Water surface elevation data were downloaded from the United States Geological Survey (USGS) for the reservoir elevation gage *TX071 08152706 LCRA Lk Marble Falls nr Marble Falls, TX.* The USGS provides LCRA data in legacy datum directly from the LCRA Hydromet: https://hydromet.lcra.org/ and adjusted to the North American Vertical Datum of 1988 (NAVD88). (U.S. Geological Survey, 2021). Elevations herein are reported in feet relative to the legacy datum. Volume and area calculations in this report are referenced to water levels provided by the USGS gage adjusted to the legacy datum. The horizontal datum used for this report is North American Datum 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet).

TWDB bathymetric and sedimentation data collection

The TWDB collected bathymetric data for Lake Marble Falls on February 12 and February 13, 2020, while daily average water surface elevations measured between 736.36 and 736.31 feet above mean sea level, respectively. Additional data were collected between Wirtz Dam and Granite Shoal on April 6, 2021, while the daily average water surface elevation measured 736.42 feet. For data collection, the TWDB used a Specialty Devices, Inc. (SDI), single-beam, multi-frequency (208 kHz, 50 kHz, and 12 kHz) sub-bottom profiling depth sounder integrated with differential global positioning system (DGPS) equipment. Data were collected along pre-planned survey lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 250 feet apart. Many of the same survey lines also were used by the TWDB for the *Volumetric and Sedimentation Survey of Lake Marble Falls, April 2007 Survey* (Texas Water Development Board, 2007). Significant differences in data coverage occur closer to the dam where the 250-foot survey transect spacing was maintained in 2020, but not during 2007. Minor differences between data coverages occur throughout as the 250-foot transect spacing was maintained throughout the 2020 survey. The depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. Each speed of sound profile, or velocity cast, is saved for further data processing. Figure 2 shows the data collection locations for the 2020 TWDB survey.

Many areas in the upper reaches of Lake Marble Falls were too shallow for the depth sounder to work properly or too shallow to access by boat. For data collection in these areas, the TWDB used a Trimble® R8-Model 4 Global Navigation Satellite System (GNSS) survey system to collect singular data points either by walking or wading. The GNSS system is a Real Time Kinematic with differential GPS (RTK-GPS) system that utilizes a base station with multiple rovers to collect data. Figure 2 shows the data collection locations for the 2021 TWDB survey.

All sounding data were collected and reviewed before sediment core sampling sites were selected. Sediment core samples are collected throughout the reservoir to assist with interpretation of the sub-bottom acoustic profiles. After analyzing the sounding data, the TWDB selected 11 locations to collect sediment core samples (Figure 2). Sediment samples were collected on August 28, 2020, in the form of three sediment cores and six grab samples using a custom-coring boat, an SDI VibeCore system, and a Ponar grab sampler. Sediment samples were not recovered at three locations.

Sediment cores are collected in 3-inch diameter aluminum tubes. Analysis of the acoustic data collected during the bathymetric survey assists in determining the depth of penetration the tube must be driven during sediment sampling. A sediment core extends from the current reservoir-bottom surface, through the accumulated sediment, and into the pre-impoundment surface. After the sample is retrieved, the core tube is cut to the level of the sediment core. The tube is capped, labeled, and transported to TWDB headquarters for further analysis.

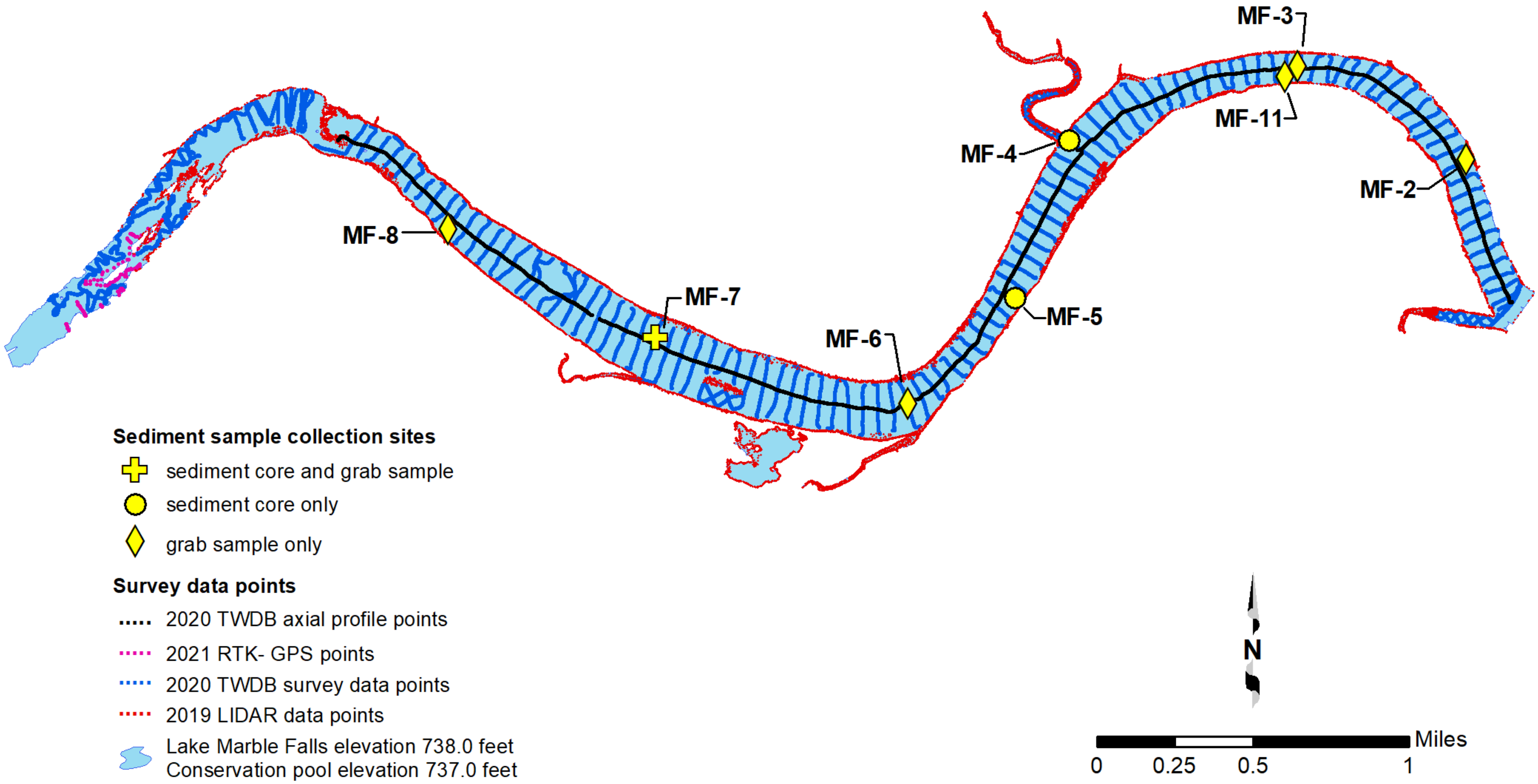


Figure 2. **2020 TWDB Lake Marble Falls survey data (*blue dots*), RTK-GPS data *(pink dots)*, sediment sampling locations (*yellow shapes*), and 2019 LIDAR data (*red dots*)**

Data processing

Model boundary

The model boundary of the reservoir was generated with Light Detection and Ranging (LIDAR) Data available from the Texas Natural Resource Information System. The LIDAR data were collected between January 4 and February 20, 2019 (Texas Water Development Board, 2021), while the daily average water surface elevation of the reservoir measured between 732.92 and 729.67 feet, respectively. The LIDAR data .las files were imported into an LAS Dataset and the dataset was converted to a raster using a cell size of 1.0 meters by 1.0 meters. A contour at 232.31856 meters equivalent to 762.2 feet NAVD88, was extracted as the upper extent of the model. The elevation of the top of the dam is 762.19 feet NAVD88. The horizontal datum of the LIDAR data is Universal Transverse Mercator (UTM) North American Datum 1983 (NAD83; meters) Zone 14, and the vertical datum is North American Vertical Datum 1988 (NAVD88; meters). The vertical datum transformation offset of 0.69 feet was used to convert from feet NAVD88 to feet above mean sea level. The contour was edited to close the contour across the top of the dam. Horizontal coordinate transformations to NAD83 State Plane Texas Central Zone (feet) coordinates were done using the ArcGIS Project tool. To get the final bathymetric model boundary at elevation 738.0 feet above mean sea level, a contour was extracted from the TIN model of the reservoir modeled up to the top of the dam. Due to a lack of data near Starcke Dam and Wirtz Dam, this contour was not representative of Lake Marble Falls at elevation 738.0 feet. This contour was manually edited, and sections re-digitized from aerial photography dated August 23, 2018, taken while the daily average water surface elevation of the reservoir measured 736.33 feet. This imagery was obtained through the Texas Imagery Service. The Texas Natural Resources Information System manages the Texas Imagery Service allowing public organizations in the State of Texas to access Google Imagery as a service using Environmental Systems Research Institute's ArcGIS software. The photographs have a resolution of 6 inches (Texas Natural Resources Information System, 2021). The 738.0-foot contour matched the photographs well, therefore, the poorly represented sections were digitized at the land water interface. The 2007 model boundary and 2020 model boundary are very similar with the exception of the exclusion in 2007 of a shallow marshy area of approximately 17 acres just downstream of Varnhagan Creek. Approximately three additional acres were identified in 2020 with the extension of Varnhagan Creek, Backbone Creek, and an unnamed creek.

LIDAR data points

To utilize the LIDAR data in the reservoir model, the LIDAR data .las files were converted to a multipoint feature class in an Environmental Systems Research Institute's ArcGIS file geodatabase filtered to include only data classified as ground points.. A topographical model of the data was generated and the ArcGIS tool Terrain to Points was used to extract points from the Terrain, or topographical model of the reservoir. The Terrain was created using the z-tolerance Pyramid Type. The points were extracted at the smallest pyramid resolution of 0.25 meters to reduce computation burden without significantly affecting the modeled topography of the coverage area. New attribute fields were added to convert the elevations from meters to feet NAVD88 and then to feet above mean sea level for compatibility with the bathymetric survey data. LIDAR data outside of the 762.19-foot contour were deleted and the feature class projected to NAD83 State Plane Texas Central Zone (feet). Much of the LIDAR data agreed well with the TWDB survey data in areas of overlap, in areas where it did not, the LIDAR data were removed. For the final bathymetric and topographic reservoir models, the LIDAR data were split to include only data within the 738.0-foot model boundary and only data within the 762.19-foot boundary but outside the 738.0-foot boundary. No further interpolation of the data in the areas with only LIDAR coverage was necessary.

RTK-GPS post-processing

Data collected using the Trimble® GPS system was downloaded from each rover's data controller (by day) and post-processed using the Trimble® Business Center (Version 4.0) software. Post-processing entails confirming project settings (e.g. vertical and horizontal datum, horizontal coordinate system) and tying the base station coordinates to Continuously Operating Reference Stations (CORS) sites to improve the precision of the project data from each rover. CORS sites are maintained by the National Geodetic Survey (NGS), an office of the National Oceanographic and Atmospheric Administration's (NOAA) National Ocean Service (National Geodetic Survey, 2021).

Triangulated Irregular Network model

Following completion of data collection, the raw data files collected by the TWDB were edited to remove data anomalies. The current bottom surface of the reservoir is automatically determined by the data acquisition software. Hydropick software, developed by TWDB staff, was used to display, interpret, and edit the multi-frequency data by manually removing data anomalies in the current bottom surface and to manually edit the pre-impoundment surfaces. The speed of sound profiles, also known as velocity casts, were used to further correct the measured depths. For each location velocity casts are collected, the harmonic mean sound speed of all the casts are calculated. From this, depths collected using one average speed of sound are corrected with an overall optimum speed of sound for each specific depth (Specialty Devices, Inc., 2018).

All data were exported into a single file, including the current reservoir bottom surface, pre-impoundment surface, and sediment thickness at each sounding location. The water surface elevation at the time of each sounding was used to convert each sounding depth to a corresponding reservoir-bottom elevation. This survey point dataset was then preconditioned by inserting a uniform grid of artificial survey points between the actual survey lines. Bathymetric elevations at these artificial points were determined using an anisotropic spatial interpolation algorithm described in the next section. This technique creates a high resolution, uniform grid of interpolated bathymetric elevation points throughout a majority of the reservoir (McEwen *et al.* 2011a). The resulting point file was used in conjunction with sounding, LIDAR, and boundary data to create volumetric and sediment Triangulated Irregular Network (TIN) models utilizing the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithm uses Delaunay's criteria for triangulation to create a grid composed of triangles from non-uniformly spaced points, including the boundary vertices (Environmental Systems Research Institute, 1995).

Spatial interpolation of reservoir bathymetry

Isotropic spatial interpolation techniques such as the Delaunay triangulation used by the 3D Analyst extension of ArcGIS are, in many instances, unable to suitably interpolate bathymetry between survey lines common to reservoir surveys. Reservoirs and stream channels are anisotropic morphological features where bathymetry at any particular location is more similar to upstream and downstream locations than to transverse locations. Interpolation schemes that do not consider this anisotropy lead to the creation of several types of artifacts in the final representation of the reservoir bottom surface and hence to errors in volume. These include artificially-curved contour lines extending into the reservoir where the reservoir walls are steep or the reservoir is relatively narrow, intermittent representation of submerged stream channel connectivity, and oscillations of contour lines in between survey lines. These artifacts reduce the accuracy of the resulting volumetric and sediment TIN models in areas between actual survey data.

To improve the accuracy of bathymetric representation between survey lines, the TWDB developed various anisotropic spatial interpolation techniques. Generally, the directionality of interpolation at different locations of a reservoir can be determined from external data sources. A basic assumption is that the reservoir profile in the vicinity of a particular location has upstream and downstream similarity. In addition, the sinuosity and directionality of submerged stream channels can be determined by directly examining the survey data, or more robustly by examining scanned USGS 7.5-minute quadrangle maps (DRGs), hypsography files (the vector format of USGS 7.5-minute quadrangle map contours), and historical aerial photographs, when available. Using the survey data, polygons are created to partition the reservoir into segments with centerlines defining directionality of interpolation within each segment. Using the interpolation definition files and survey data, the current reservoir-bottom elevation, pre-impoundment elevation, and sediment thickness are calculated for each point in the high-resolution uniform grid of artificial survey points. The reservoir boundary, artificial survey points grid, and survey data points are used to create volumetric and sediment TIN models representing reservoir bathymetry and sediment accumulation throughout the reservoir. Specific details of this interpolation technique can be found in the HydroTools manual (McEwen and others, 2011a) and in McEwen and others (2011b).

In areas inaccessible to survey data collection, such as small coves and shallow upstream areas of the reservoir, linear interpolation is used for volumetric and sediment accumulation estimations (McEwen and others, 2011a). Although LIDAR was utilized, linear interpolation was necessary to accurately model features in the areas between survey data and LIDAR data. Linear interpolation results in improved elevation-capacity and elevation-area calculations.

Figure 3 illustrates typical results from application of the anisotropic interpolation as applied to Lake Marble Falls. In Figure 3A, deeper channels and steep slopes indicated by surveyed cross-sections are not continuously represented in areas between survey cross-sections. This is an artifact of the TIN generation routine rather than an accurate representation of the physical bathymetric surface. Inclusion of interpolation points in creation of the volumetric TIN model, represented in Figure 3B, directs Delaunay triangulation to better represent the reservoir bathymetry between survey cross-sections. The bathymetry shown in Figure 3C was used in computing reservoir elevation-capacity (Appendix A) and elevation-area (Appendix B) tables.

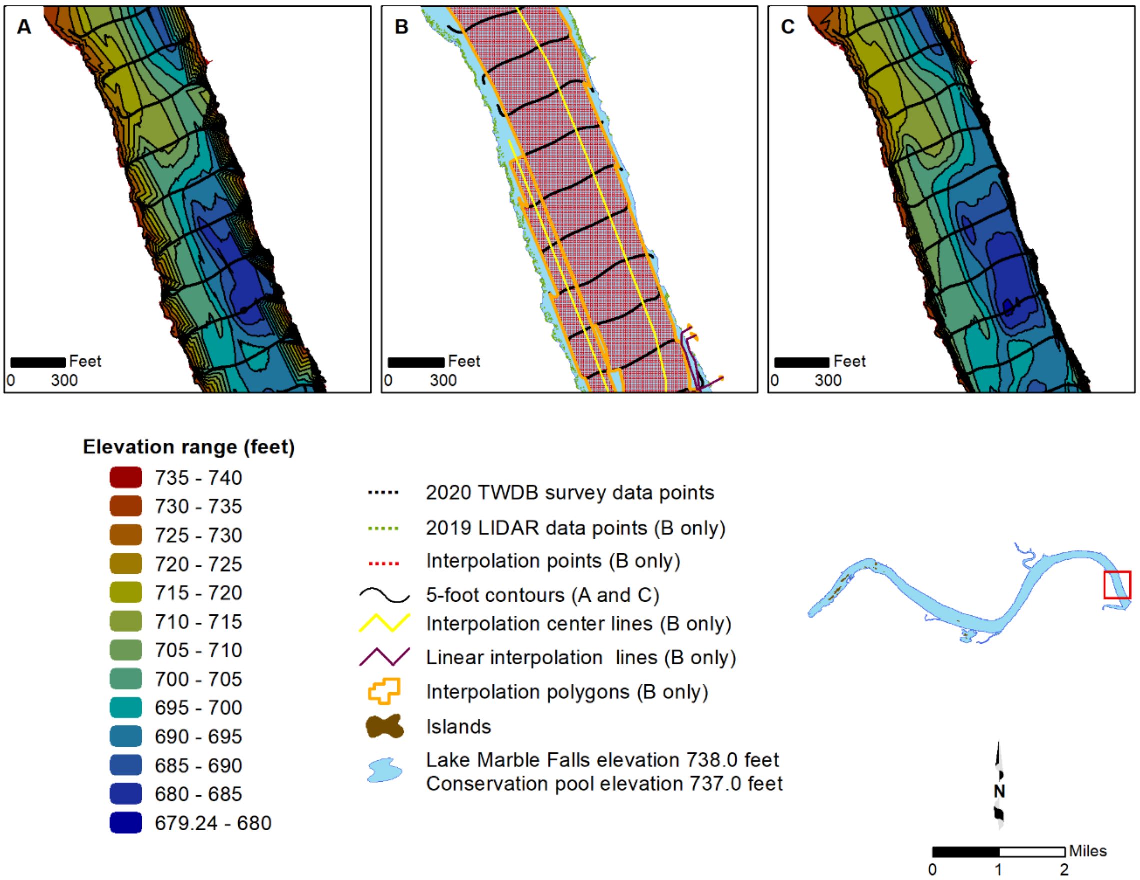


Figure 3. **Anisotropic spatial interpolation as applied to Lake Marble Falls sounding data; A) bathymetric contours without interpolated points, B) sounding points (*black*) and interpolated points (*red*), C) bathymetric contours with interpolated points.**

Area, volume, and contour calculation

Volumes and areas were computed for the entire reservoir at 0.1-foot intervals, from 679.20 to 738.00 feet above mean sea level. The bathymetric elevation-capacity table and elevation-area table, based on the 2020 survey and analysis, are presented in Appendices A and B, respectively. The bathymetric capacity curve is presented in Appendix C, and the bathymetric area curve is presented in Appendix D. For the topographic TIN model, volumes and areas were computed for the entire reservoir at 0.1-foot intervals, from 679.20 to 761.5 feet above mean sea level. The topographic elevation-capacity table and topographic elevation-area table developed from the 2020 survey and analysis are presented in Appendices E and F, respectively. The topographic capacity curve is presented in Appendix G, and the topographic area curve is presented in Appendix H.

The volumetric bathymetric TIN model was converted to a raster representation using a cell size of 1 foot by 1 foot. The raster data then were used to produce three figures: (1) an elevation relief map representing the topography of the reservoir bottom (Figure 4); (2) a depth range map showing shaded depth ranges for Lake Marble Falls (Figure 5); and, (3) a 5-foot contour map (Figure 6).

Figure 4

Lake Marble Falls

Elevation relief map

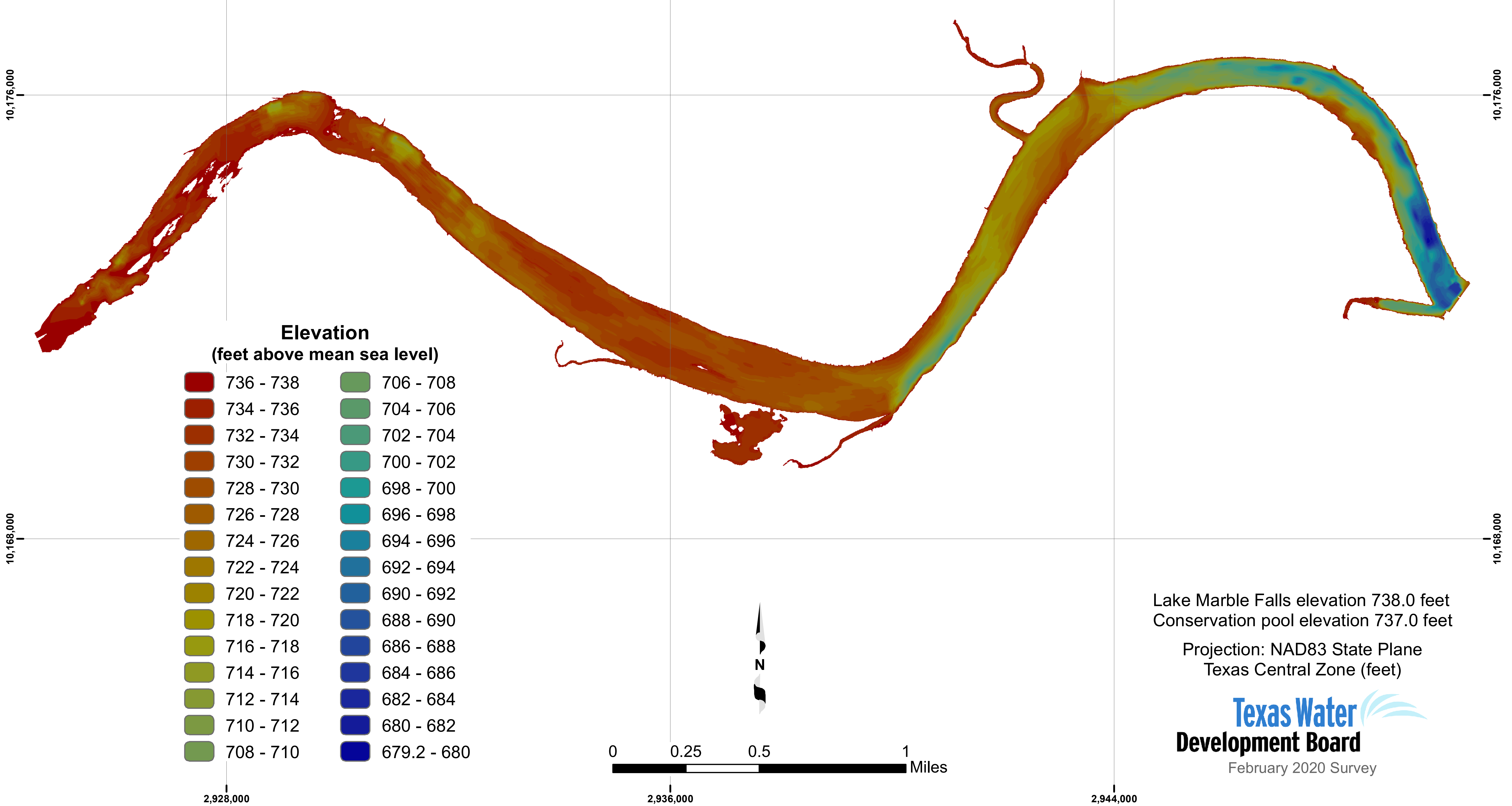
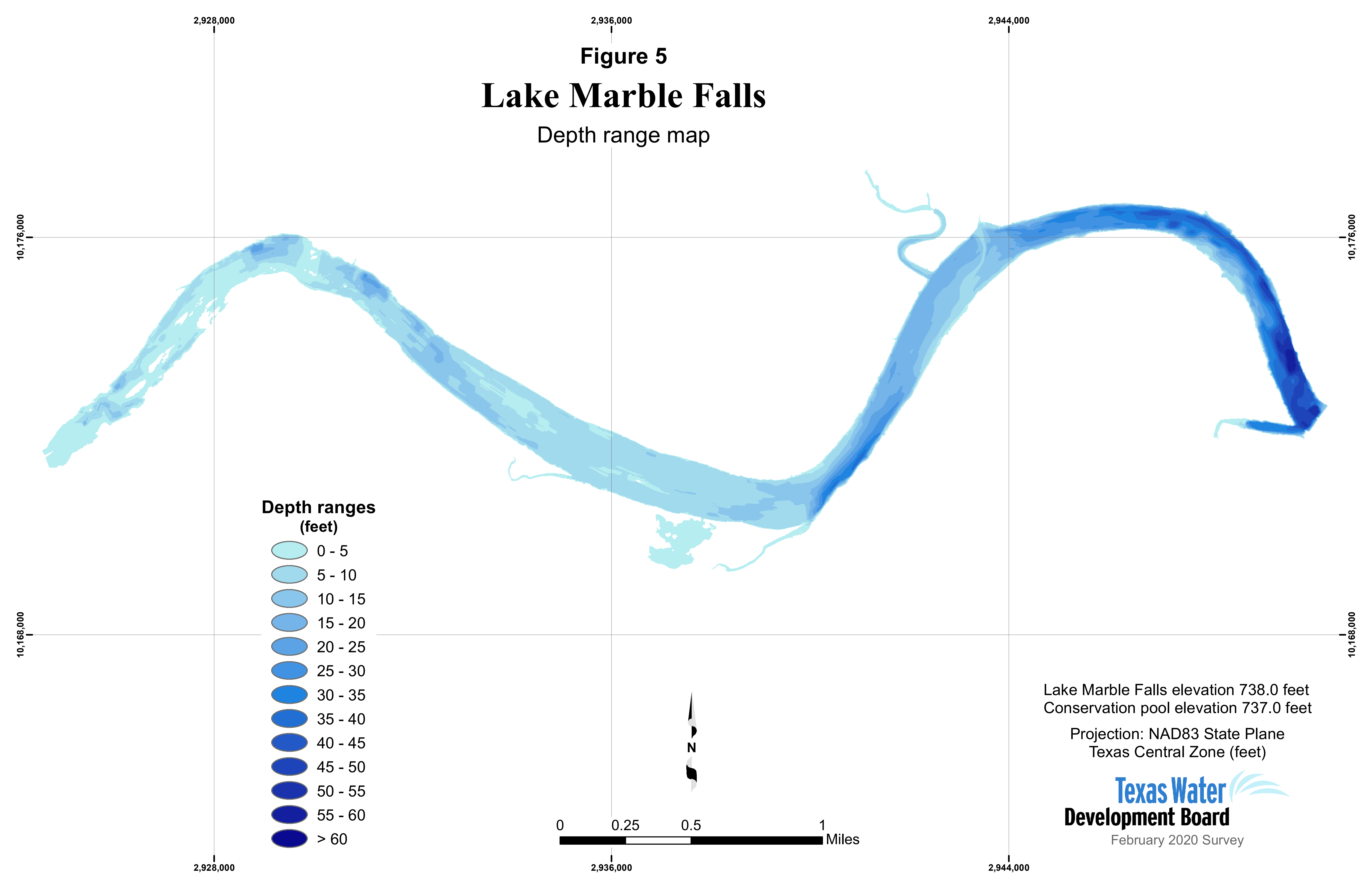


Figure 5

Lake Marble Falls

Depth range map



Analysis of sediment data from Lake Marble Falls

Sedimentation in Lake Marble Falls was determined by analyzing the acoustic signal returns of all three depth sounder frequencies using customized software called Hydropick. While the 208 kHz signal is used to determine the current bathymetric surface, the 208 kHz, 50 kHz, and 12 kHz are analyzed to determine the reservoir bathymetric surface at the time of initial impoundment, *i.e.*, pre-impoundment surface. Sediment core samples collected in the reservoir are correlated with the acoustic signals in each frequency to assist in identifying the pre-impoundment surface. The difference between the current surface bathymetry and the pre-impoundment surface bathymetry yields a sediment thickness value at each sounding location.

The texture or general make-up of the grab samples was analyzed on the boat as they were collected. Sediment cores were analyzed at TWDB headquarters in Austin. Each core was split longitudinally and analyzed to identify the location of the pre-impoundment surface. The pre-impoundment surface was identified within the sediment core using the following methods: (1) a visual examination of the sediment core for terrestrial materials, such as leaf litter, tree bark, twigs, intact roots, *etc.*, concentrations of which tend to occur on or just below the pre-impoundment surface; (2) recording changes in texture from well sorted, relatively fine-grained sediment to poorly sorted mixtures of coarse and fine-grained materials; and, (3) identifying variations in the physical properties of the sediment, particularly sediment water content and penetration resistance with depth (Van Metre and others, 2004). Total sediment core length, post impoundment sediment thickness, and pre-impoundment thickness were recorded. Physical characteristics of the sediment core, such as Munsell soil color, texture, relative water content, and presence of organic materials were recorded (Table 2).

Table 2. Sediment core sample analysis data.

Sediment core sample	Easting[a] (feet)	Northing[a] (feet)	Total core sample / post-impoundment sediment (inches)	Sediment core description[b]		Munsell soil color
MF-2	2949259.73	10174861.44	grab[c]	post-impoundment	fine silt	N/A
			N/A	N/A	no recovery	N/A
MF-3	2946408.72	10176432.59	grab[c]	post-impoundment	silty sand, gritty, coarse	N/A
			N/A	N/A	no recovery	N/A
MF-4	2942546.00	10175179.88	17.0 / 17.0	post-impoundment	0.0–17.0” low to moderate water content, coarse sand, rock, and thin layer of silt on top, 2.5-inch by 2-inch rock at 12 to 14 inches, no organic matter present	5Y 5/2 olive gray
MF-5	2941635.29	10172522.91	7.5 / 7.5	post-impoundment	0.0–7.5” low to moderate water content, small to medium sized gravel and rock, thin layer of silt on top, no organic matter present	5Y 5/2 olive gray
MF-6	2939826.78	10170736.16	grab[c]	post-impoundment	fine silt, coarse sand, and small gravel	N/A
			N/A	N/A	no recovery	N/A
MF-7	2935554.25	10171845.64	grab[c]	post-impoundment	coarse sand, small to medium sized gravel (less than 3-inches), fine layer of silt	N/A
			8.5 / 8.5	post-impoundment	low to moderate water content, coarse sand, small to medium sized gravel, rock (less than 3-inches), no organic matter present	5Y 5/2 olive gray
MF-8	2932030.87	10173702.27	grab[c]	post-impoundment	fine silt, coarse sand, and small gravel	N/A
			N/A	N/A	no recovery after multiple attempts using core catchers	N/A
MF-11	2946202.50	10176257.66	grab[c]	post-impoundment	fine silt, coarse sand, and small gravel	N/A
			N/A	N/A	no recovery	N/A

a. Coordinates are based on NAD83 State Plane Texas Central System (feet)
b. Sediment core samples are measured in inches with zero representing the current bottom surface
c. Grab samples were collected using a Ponar dredge sampler

A photograph of sediment samples MF-7 (for location, refer to Figure 2) are shown in Figure 7. In the photo of the sediment core sample on the left, the base, or deepest part of the sample is denoted by the blue line. All 8.5 inches of sediment recovered was interpreted to be post-impoundment sediment. A pre-impoundment boundary was not evident. For comparison, a photograph of the grab sample is shown on the right. Both core and grab sample contained coarse sand and small to medium sized gravel. Analysis for each sediment core and grab sample followed a similar procedure. All sediment recovered was interpreted to be post-impoundment sediment with no pre-impoundment surface identified in the sediment samples.

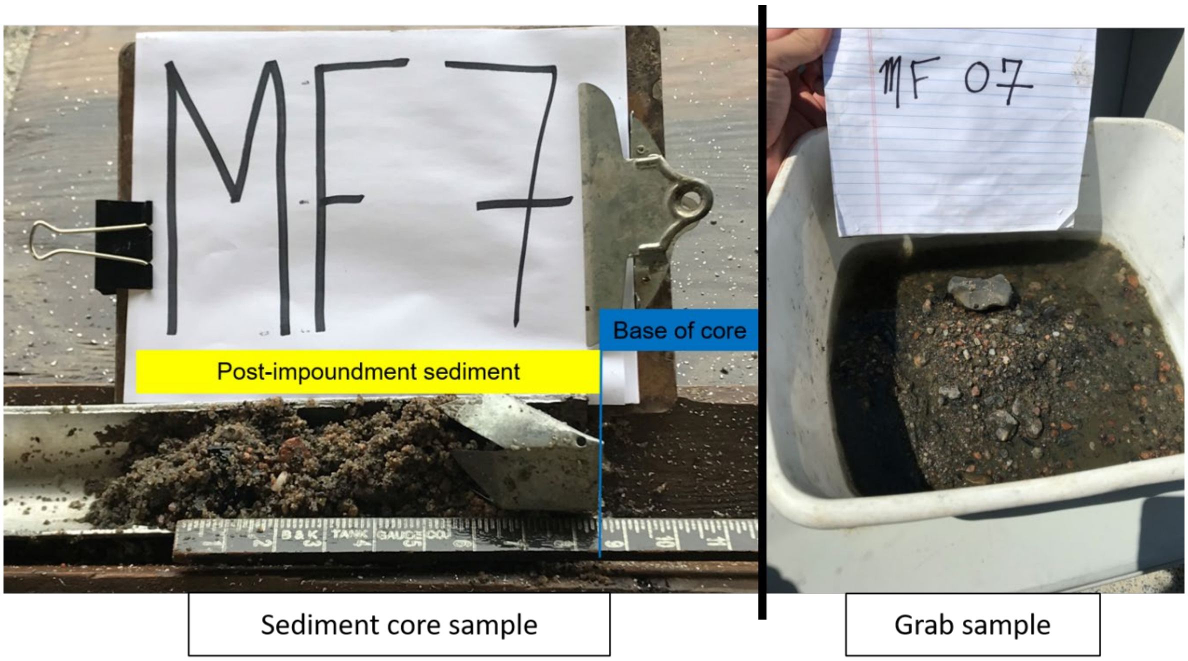


Figure 7. Sediment sample MF-7. In the sediment core on the left, the 8.5 inches of sediment was interpreted to be post-impoundment sediment (identified by the yellow box). Pre-impoundment sediment layers were not identified. Similar sediment was retrieved by the grab sample as seen on the right.

Figure 8 illustrates the relationships between acoustic signal returns and the depositional layering seen in sediment cores. In this example, sediment core MF-7 is shown correlated with each frequency: 208 kHz, 50 kHz, and 12 kHz. The current bathymetric surface is determined based on signal returns from the 208 kHz transducer as represented by the top red line in Figure 8. The pre-impoundment surface is identified by comparing boundaries observed in the 208 kHz, 50 kHz, and 12 kHz signals to the location of the pre-impoundment surface of the sediment core sample. Many layers of sediment may be identified during analysis based on changes in observed characteristics such as water content, organic matter content, and sediment particle size, and each layer is classified as either post-impoundment or pre-impoundment. Yellow boxes represent post-impoundment sediments identified in the sediment core. Blue boxes indicate pre-impoundment sediments. No pre-impoundment sediment was identified in the example.

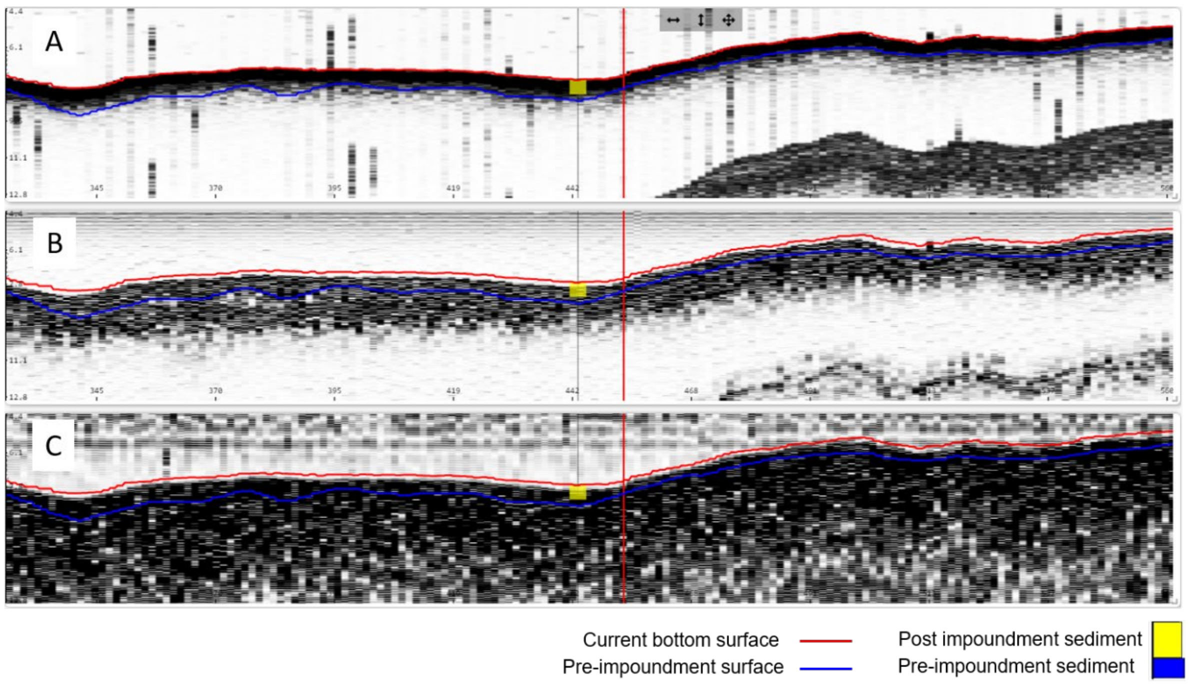


Figure 8. Sediment core sample MF-7 compared with acoustic signal returns. A) 208 kHz frequency, B) 50 kHz frequency, and C) 12 kHz frequency.

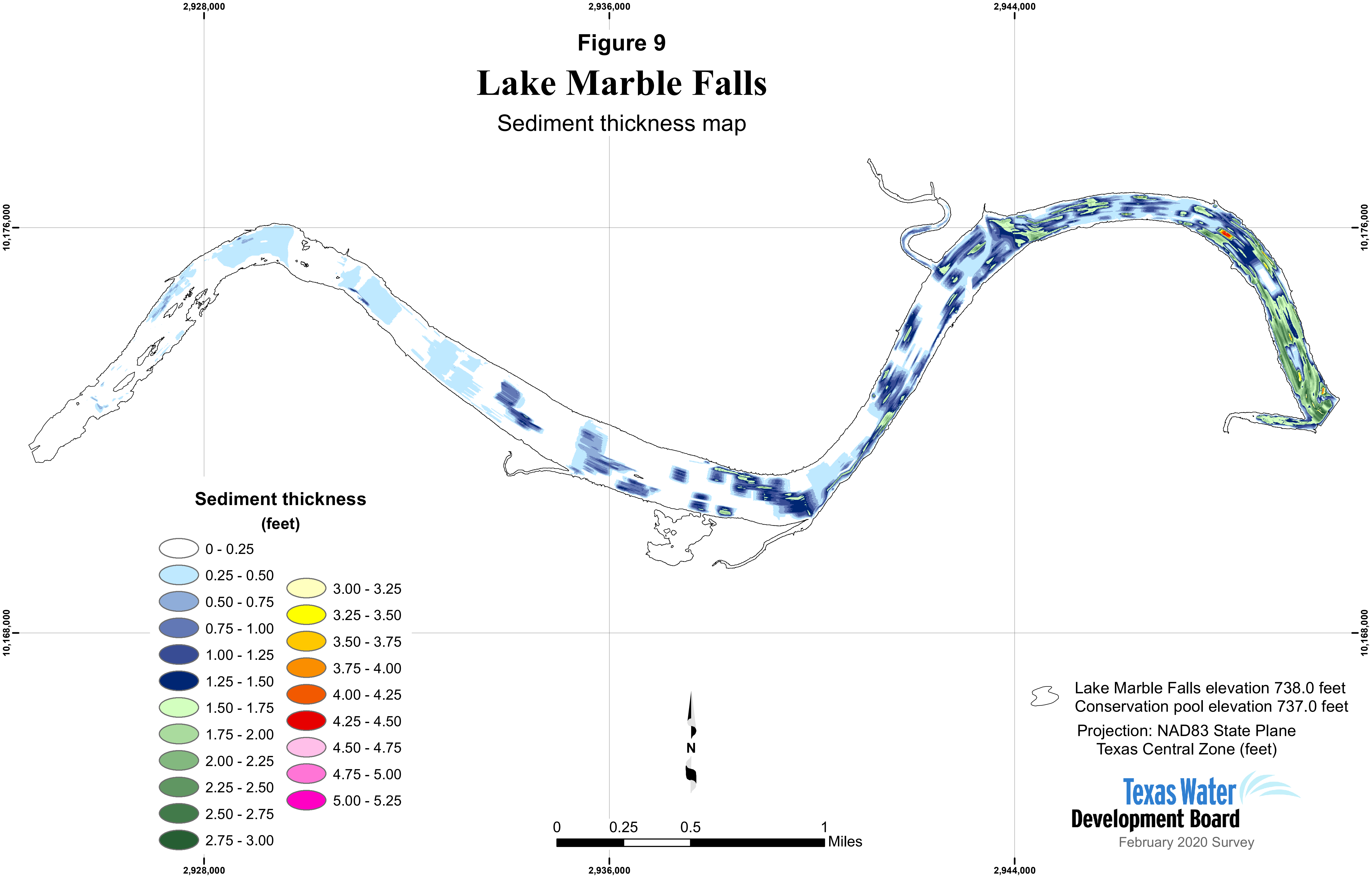
The pre-impoundment boundary in sediment core MF-7 most closely aligned with the different layers picked up by the 200 kHz acoustic returns (Figure 8). The pre-impoundment surface is first identified along cross-sections for which sediment core samples were collected. This information then is used as a guide for identifying the pre-impoundment surface along cross-sections where sediment core samples were not collected.

After the pre-impoundment surface for all cross-sections is identified, a pre-impoundment TIN model and a sediment thickness TIN model are created. Pre-impoundment elevations and sediment thicknesses are interpolated between surveyed cross-sections using HydroTools with the same interpolation definition file used for bathymetric interpolation. For the purposes of TIN model creation, the TWDB assumed the sediment thickness at each LIDAR data point and the reservoir boundary was 0 feet (defined as the 738.0-foot elevation contour). The sediment thickness TIN model was converted to a raster representation using a cell size of 2 feet by 2 feet and was used to produce a sediment thickness map (Figure 9). Elevation-capacity and elevation-area tables were computed from the pre-impoundment TIN model for the purpose of calculating the total volume of accumulated sediment.

Figure 9

Lake Marble Falls

Sediment thickness map



Survey results

Volumetric survey

The 2020 TWDB volumetric survey indicates Lake Marble Falls has a total reservoir capacity of 8,568 acre-feet and encompasses 645 acres at top of flood gate elevation (738.54 feet above mean sea level). The 2020 TWDB volumetric survey indicates Lake Marble Falls has a total reservoir capacity of 7,597acre-feet and encompasses 613 acres at conservation pool elevation (737.00 feet above mean sea level). Current area and capacity estimates are compared to previous area and capacity estimates at different elevations in Table 3. Because of differences in past and present survey methodologies, direct comparison of volumetric surveys to others to estimate loss of area and capacity can be unreliable.

Table 3. Current and previous survey capacity and surface area estimates.

Survey	Surface area (acres)	Total capacity (acre-feet)	Source
Top of flood gates elevation (738.54 feet above mean sea level)			
TWDB 2007[a]	655	8,142	Texas Water Development Board, 2007
TWDB 2020	645	8,568	
Elevation 738.00 feet above mean sea level			
LCRA 1964	780	8,760	Texas Water Development Board, 1971
TWDB 2007[a]	631	7,795	Texas Water Development Board, 2007
TWDB 2020	633	8,221	
Top of conservation pool elevation (737.00 feet above mean sea level)			
TWDB 2007	591	7,186	Texas Water Development Board, 2007
TWDB 2020	613	7,597	

[a] 2007 TWDB area linearly extrapolated to 739.04 feet NGVD29 (738.54 feet above mean sea level), capacities calculated from extrapolated areas.

Volumetric survey accuracy assessment

Axial profile data were collected to evaluate the accuracy of the volumetric survey. For location of the axial profile points see Figure 2. For other uses of the axial profile data see the section below titled “Axial profile”. First, the accuracy of the survey data was assessed by calculating the root mean square error (RMSE) of the differences between the axial profile points and the survey data points within 1.5 feet. Second, the accuracy of the interpolated data was assessed by calculating the RMSE of the differences between the axial profile points and the model surface. The RMSE of the survey data points is 0.33 feet and the RMSE of the model surface is 1.98 feet. Using the RMSE value of 1.98 as the range of uncertainty for the volumetric survey, 1.98 feet was added to and subtracted from the survey data and interpolated data points. Elevation-area-capacity tables of the resulting models provide the range of potential error throughout the survey. Results at conservation pool elevation suggest the total reservoir capacity estimate is accurate to within ± 12.7 percent (± 1,042 acre-feet). The accuracy assessment highlights the difficulty in modeling the highly variable terrain of undulating, irregular sandy and gravelly bottom found throughout Lake Marble Falls. A sand bar or deep spot in between survey lines may not be represented properly in the model and therefore not match actual measurements, i.e. axial profile points. As depth increases the percent of uncertainty increases as a small change in elevation can lead to a much larger percent change in area, and therefore, capacity.

Sedimentation survey

The 2020 TWDB sedimentation survey measured 320 acre-feet of sediment. The sedimentation survey indicates sediment accumulation is greatest near the dam. Comparison of capacity estimates of Lake Marble Falls derived using differing methodologies are provided in Table 4 for sedimentation rate calculation. The 2020 TWDB sedimentation survey indicates Lake Marble Falls has lost capacity at an average of 4.6 acre-feet per year since impoundment due to sedimentation below elevation 738.00 feet above mean sea level. Long-term trends indicate Lake Marble Falls loses capacity at an average of 9.6 acre-feet per year since impoundment due to sedimentation below elevation 738.00 feet above mean sea level (Figure 10). Differences in methodology may also contribute to differences between these surveys.

Although sediment was identified in Lake Marble Falls, it is likely that this is sediment that has been re-distributed throughout the reservoir and not post-impoundment sediment deposits. Comparison of the 2020 sediment core and sediment grab sample sediment with 2007 sediment samples show very similar sediment was collected during both surveys. While some silt was found in 2020 indicating there is post-impoundment sediment in the reservoir, it is negligible. Lake Marble Falls is a small highly riverine lake. Any suspended sediment that flows in may not have time to settle out. The sediment identified as post-impoundment in 2020 is likely sediment that has shifted in the reservoir since the last survey due to high flow events, particularly a record setting flood in October of 2018. All the sediment collected in 2007 was classified as fluvial in origin suggesting it was pre-impoundment sediment. Comparison of the current bottom surface with the 2007 surface show general scour and deposition trends throughout the reservoir (Figure 11).

Table 4. Average annual capacity loss comparisons for Lake Marble Falls.

Survey	Elevation 738.00 feet above mean sea level (acre-feet)		
LCRA 1964[a]	8,760	<>	<>
TWDB 2007	<>	7,795	<>
TWDB pre-impoundment estimate based on 2020 survey	<>	<>	8,541
2020 volumetric survey	8,221	8,221	8,221
Volume difference (acre-feet) Percent change	539 6.1%	-426 -5.5%	320 3.7%
Number of years	56	13	69[b]
Capacity loss rate (acre-feet/year)	9.6	-32.8	4.6

a. Source: (Texas Water Development Board, 1971)
b. Deliberate impoundment of Lake Marble Falls began in July 1951

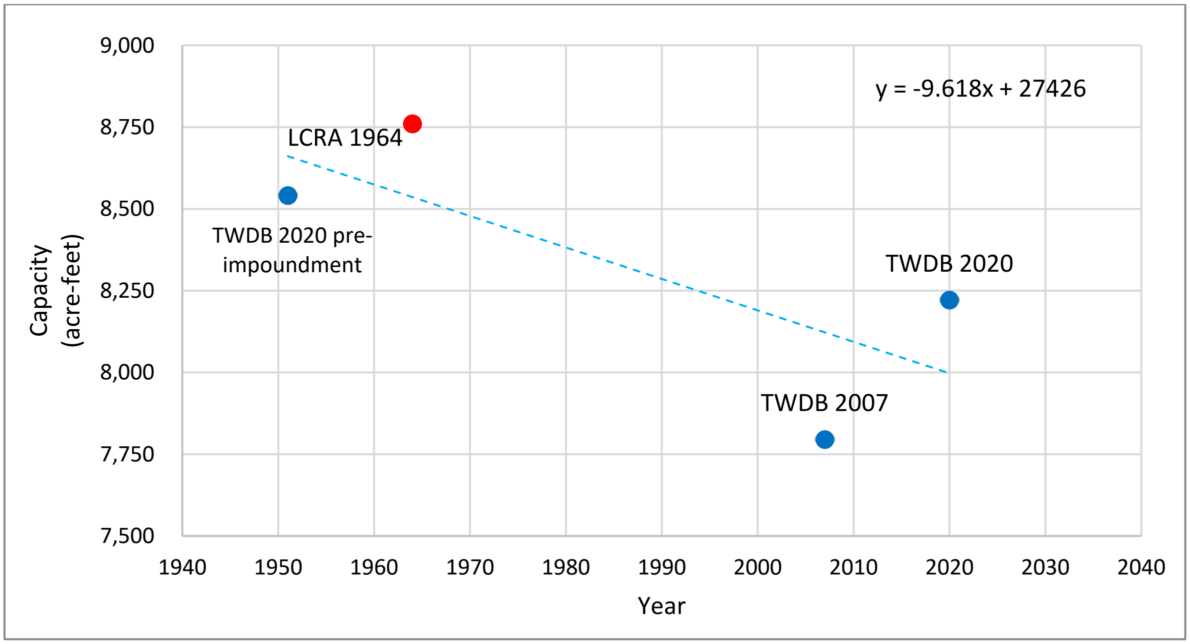


Figure 10. **Plot of current and previous capacity estimates (acre-feet) at elevation 738.00 feet for Lake Marble Falls. Capacity estimates for each TWDB survey plotted as blue dots and other surveys as red dots. The blue trend line illustrates the total average loss of capacity through 2020.**

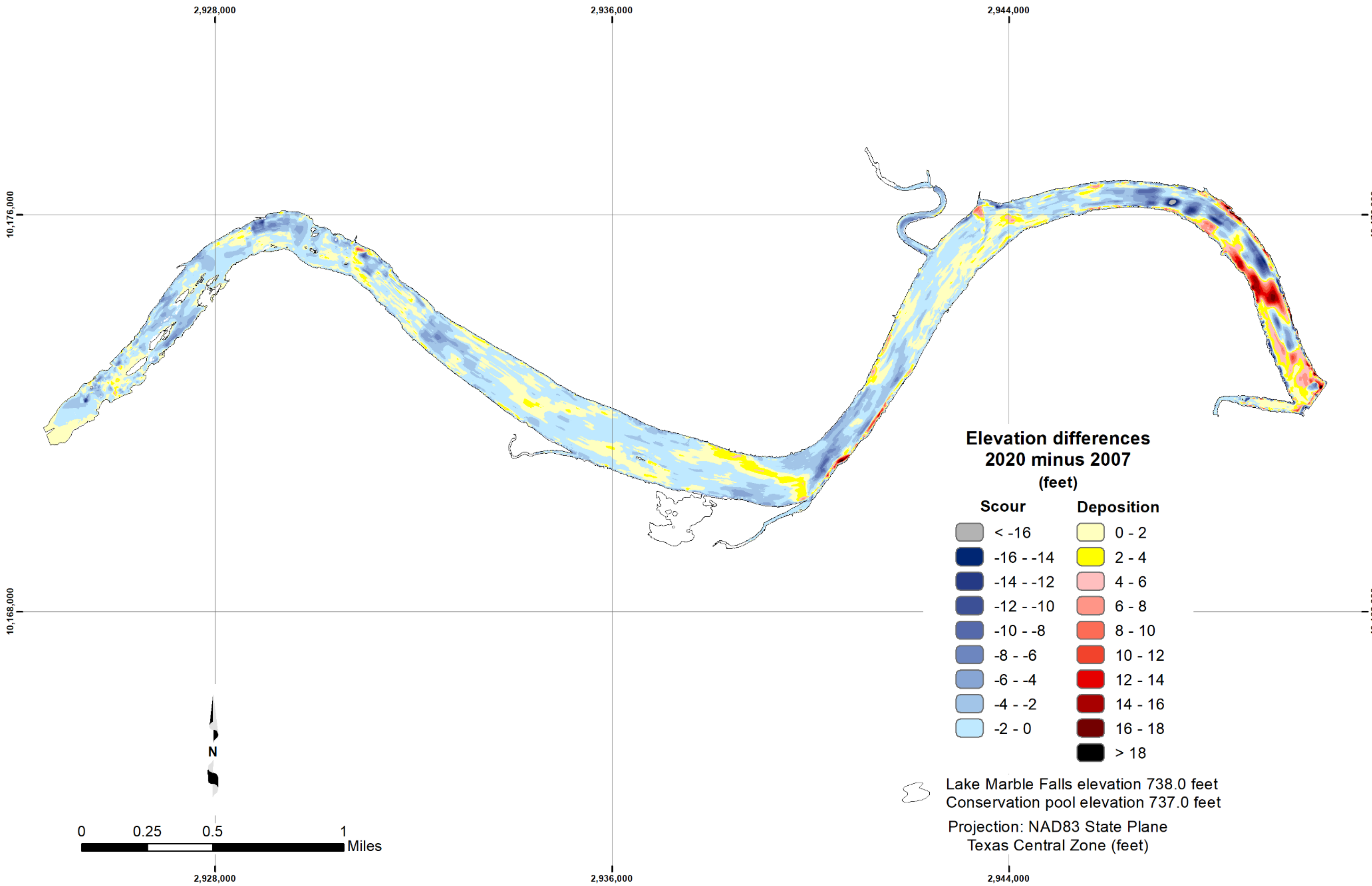


Figure 11. Bathymetric differences between 2020 and 2007 bottom surfaces

Axial profile

The axial profile of the reservoir, showing both the 2020 current and pre-impoundment surfaces, is plotted in Appendix I. Also presented in Appendix I are a map, depicting the TWDB location of the axial profile, and a table listing the coordinates of each vertex defining the axial line.

Identification of the pre-impoundment surface on the axial profile was based on the acoustic returns identified in the cross-sections where sediment cores were collected. Sediment core sites were selected to recollect cores where previously collected in 2007 and to correlate with unique acoustic returns throughout the reservoir. Pre-impoundment acoustic signature interpretation was refined based on the agreement between intersecting data and applied during pre-impoundment identifications throughout the reservoir.

Recommendations

The TWDB recommends a volumetric survey of Lake Marble Falls within a 10-year timeframe or after a major high flow event to assess changes in reservoir capacity and to further improve estimates of sediment accumulation rates. Due to the irregular bottom, riverine behavior of the reservoir, and responses to high flow events, a multibeam survey should be considered to more accurately measure capacity and identify changes in the reservoir bottom.

TWDB contact information

For more information about the TWDB Hydrographic Survey Program, visit www.twdb.texas.gov/surfacewater/surveys. Any questions regarding the TWDB Hydrographic Survey Program or this report may be addressed to: Hydrosurvey@twdb.texas.gov.

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Appendix A

Lake Marble Falls

RESERVOIR BATHYMETRIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — February 2020 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 737.0 feet

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
679	0	0	0	0	0	0	0	0	0	0
680	0	0	0	0	0	0	0	0	0	0
681	0	0	1	1	1	1	1	1	1	1
682	1	1	1	2	2	2	2	2	2	2
683	3	3	3	3	3	3	4	4	4	4
684	4	5	5	5	5	5	6	6	6	7
685	7	7	7	8	8	8	9	9	9	9
686	10	10	10	11	11	11	12	12	13	13
687	13	14	14	15	15	15	16	16	17	17
688	18	18	19	19	20	20	21	21	22	23
689	23	24	24	25	26	26	27	28	28	29
690	30	31	31	32	33	34	35	36	36	37
691	38	39	40	41	42	43	44	45	47	48
692	49	50	51	53	54	55	57	58	59	61
693	62	64	65	66	68	70	71	73	74	76
694	78	79	81	83	85	86	88	90	92	94
695	96	98	100	102	104	107	109	111	113	115
696	118	120	122	125	127	129	132	134	137	139
697	142	144	147	149	152	154	157	160	163	165
698	168	171	174	177	180	183	185	188	191	195
699	198	201	204	207	210	213	217	220	223	227
700	230	233	237	240	244	247	251	254	258	262
701	265	269	273	277	280	284	288	292	296	300
702	304	308	312	316	320	324	329	333	337	341
703	346	350	355	359	364	368	373	378	382	387
704	392	397	402	407	412	417	422	427	432	437
705	443	448	453	459	464	470	475	481	487	492
706	498	504	510	516	522	528	534	541	547	553
707	559	566	572	578	585	591	598	605	611	618
708	625	632	638	645	652	659	666	673	681	688
709	695	702	710	717	725	732	740	748	756	763
710	771	779	787	795	804	812	820	828	837	845
711	853	862	870	879	888	896	905	914	923	932
712	941	950	959	968	977	986	996	1,005	1,014	1,024
713	1,033	1,043	1,052	1,062	1,072	1,081	1,091	1,101	1,111	1,121
714	1,131	1,141	1,151	1,161	1,171	1,181	1,191	1,202	1,212	1,222
715	1,233	1,243	1,254	1,264	1,275	1,285	1,296	1,307	1,317	1,328
716	1,339	1,350	1,361	1,372	1,383	1,394	1,405	1,416	1,428	1,439
717	1,450	1,462	1,473	1,484	1,496	1,508	1,519	1,531	1,543	1,555
718	1,567	1,579	1,591	1,603	1,615	1,627	1,640	1,652	1,665	1,677
719	1,690	1,703	1,716	1,729	1,743	1,756	1,770	1,783	1,797	1,811
720	1,825	1,839	1,854	1,868	1,883	1,898	1,913	1,928	1,943	1,958
721	1,974	1,989	2,005	2,021	2,037	2,053	2,069	2,086	2,103	2,119
722	2,136	2,153	2,171	2,188	2,205	2,223	2,241	2,258	2,276	2,294
723	2,312	2,331	2,349	2,367	2,386	2,405	2,423	2,442	2,461	2,480
724	2,500	2,519	2,538	2,558	2,578	2,598	2,618	2,638	2,658	2,679
725	2,699	2,720	2,741	2,762	2,783	2,805	2,826	2,848	2,870	2,892
726	2,915	2,937	2,960	2,983	3,006	3,029	3,053	3,076	3,100	3,124
727	3,149	3,173	3,198	3,223	3,249	3,275	3,300	3,327	3,353	3,380
728	3,407	3,434	3,462	3,490	3,518	3,547	3,576	3,606	3,635	3,666
729	3,696	3,727	3,759	3,790	3,823	3,856	3,889	3,923	3,957	3,992
730	4,028	4,064	4,101	4,138	4,176	4,214	4,253	4,292	4,332	4,372
731	4,413	4,455	4,497	4,540	4,583	4,626	4,670	4,715	4,759	4,805
732	4,850	4,896	4,943	4,990	5,037	5,085	5,133	5,181	5,230	5,279
733	5,329	5,379	5,430	5,481	5,532	5,584	5,636	5,689	5,742	5,796
734	5,851	5,905	5,960	6,016	6,071	6,127	6,183	6,240	6,297	6,353
735	6,411	6,468	6,526	6,583	6,641	6,700	6,758	6,817	6,875	6,934
736	6,994	7,053	7,113	7,173	7,233	7,293	7,353	7,414	7,475	7,536
737	7,597	7,659	7,720	7,782	7,844	7,906	7,969	8,032	8,094	8,157
738	8,221									

Appendix B

Lake Marble Falls

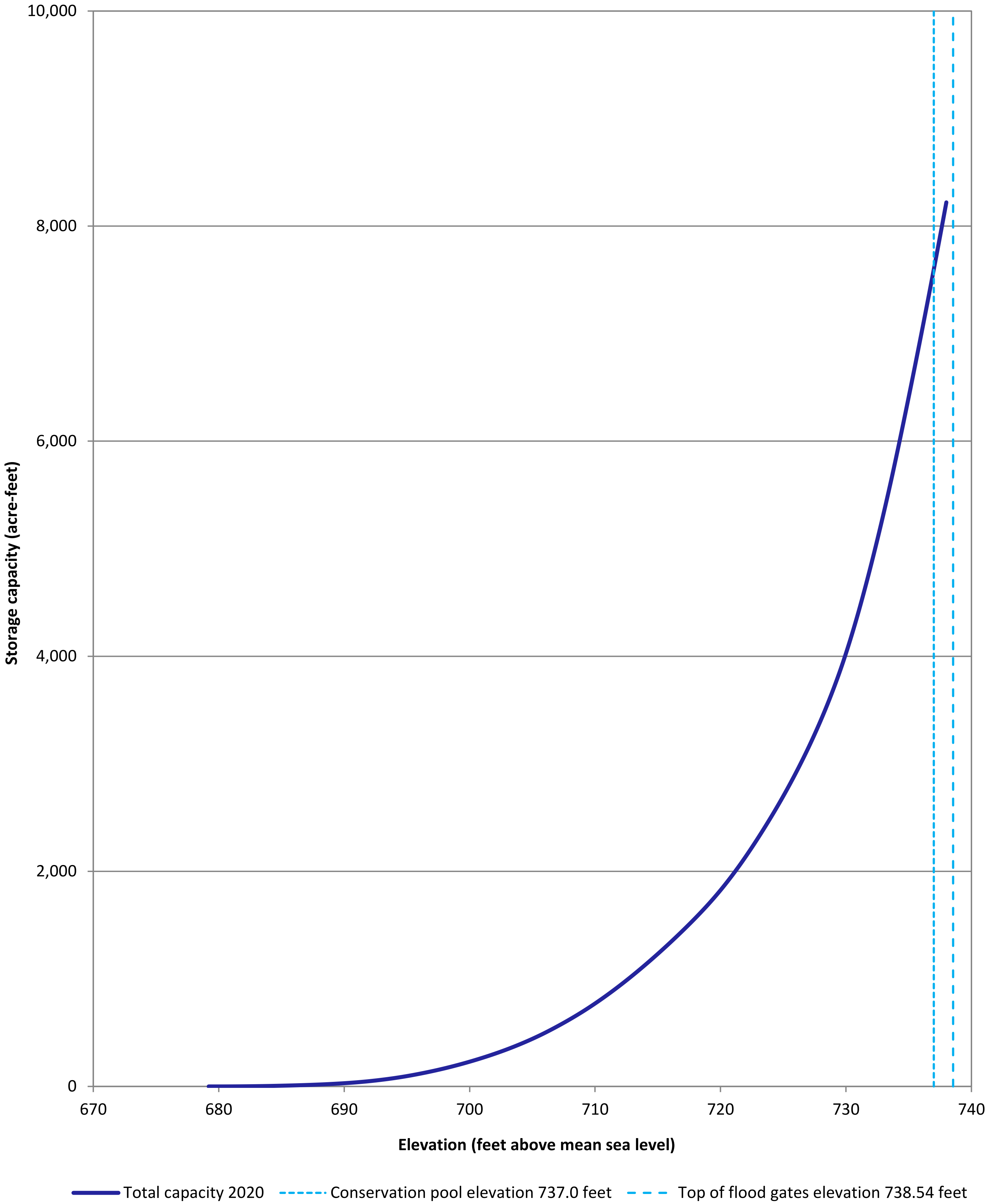
RESERVOIR BATHYMETRIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — February 2020 Survey

AREA IN ACRES — Conservation pool elevation 737.0 feet

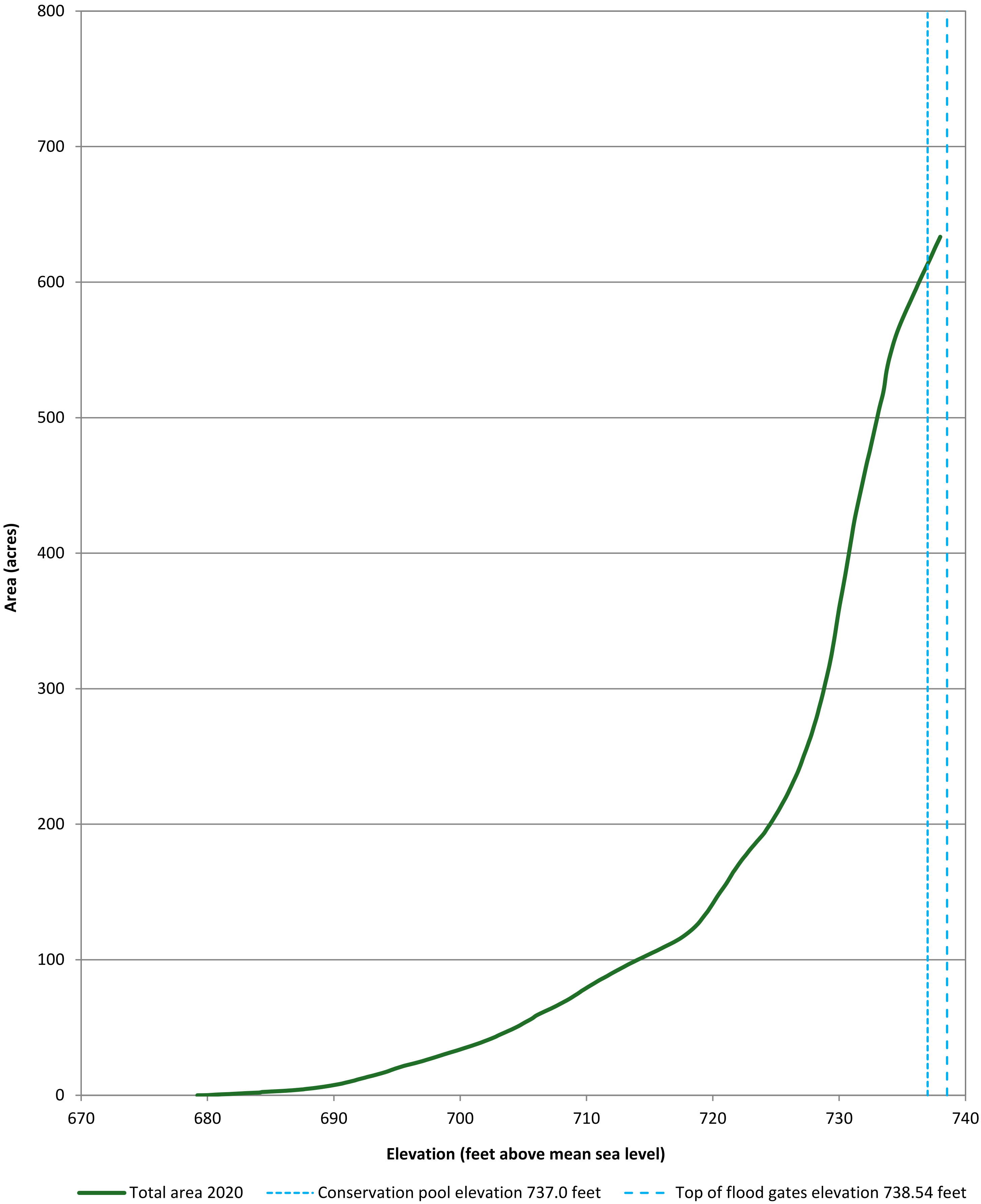
ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
679	0	0	0	0	0	0	0	0	0	0
680	0	0	0	0	0	0	0	1	1	1
681	1	1	1	1	1	1	1	1	1	1
682	1	1	1	1	1	1	1	1	1	2
683	2	2	2	2	2	2	2	2	2	2
684	2	2	2	2	2	3	3	3	3	3
685	3	3	3	3	3	3	3	3	3	3
686	3	3	3	3	3	4	4	4	4	4
687	4	4	4	4	4	4	4	5	5	5
688	5	5	5	5	5	5	6	6	6	6
689	6	6	6	6	7	7	7	7	7	7
690	8	8	8	8	8	8	9	9	9	9
691	9	10	10	10	10	11	11	11	11	12
692	12	12	12	13	13	13	13	14	14	14
693	14	15	15	15	15	16	16	16	16	17
694	17	17	17	18	18	18	19	19	19	20
695	20	20	21	21	21	22	22	22	22	23
696	23	23	23	23	24	24	24	24	25	25
697	25	25	26	26	26	27	27	27	27	28
698	28	28	29	29	29	30	30	30	30	31
699	31	31	32	32	32	32	33	33	33	34
700	34	34	34	35	35	35	36	36	36	37
701	37	37	37	38	38	38	39	39	39	40
702	40	41	41	41	42	42	42	43	43	44
703	44	45	45	45	46	46	47	47	47	48
704	48	49	49	50	50	50	51	51	52	53
705	53	54	54	55	55	56	56	57	57	58
706	59	59	60	60	61	61	61	62	62	63
707	63	64	64	65	65	65	66	66	67	67
708	68	68	69	69	70	70	71	71	72	73
709	73	74	74	75	76	76	77	78	78	79
710	79	80	80	81	81	82	83	83	84	84
711	85	85	86	86	87	87	88	88	89	89
712	90	90	91	92	92	93	93	94	94	94
713	95	96	96	97	97	97	98	98	99	99
714	100	100	101	101	102	102	102	103	103	104
715	104	105	105	106	106	106	107	107	108	108
716	109	109	110	110	111	111	112	112	112	113
717	113	114	115	115	116	116	117	118	118	119
718	120	120	121	122	123	124	124	125	126	127
719	129	130	131	132	133	135	136	137	139	140
720	141	143	144	146	147	149	150	151	153	154
721	155	157	158	160	161	163	164	166	167	168
722	170	171	172	174	175	176	177	178	180	181
723	182	183	184	185	186	187	188	189	191	192
724	193	194	195	197	198	200	201	202	204	206
725	207	209	210	212	213	215	217	219	220	222
726	224	226	228	230	232	234	236	238	240	243
727	245	248	251	253	255	258	261	263	266	269
728	272	275	278	282	285	289	292	296	300	304
729	308	312	316	321	325	331	336	342	348	354
730	360	365	370	375	380	385	390	396	401	407
731	413	419	424	428	433	437	441	446	450	454
732	459	463	467	471	475	479	483	487	491	495
733	499	504	508	512	515	519	525	532	537	541
734	545	548	552	555	558	561	563	566	568	570
735	573	575	577	579	581	583	585	587	589	591
736	593	595	598	600	602	604	606	608	609	611
737	613	615	617	619	621	624	626	628	629	631
738	633									



Lake Marble Falls
February 2020 Survey
Prepared by: TWDB

Appendix C: Bathymetric capacity curve



Lake Marble Falls
February 2020 Survey
Prepared by: TWDB

Appendix D: Bathymetric area curve

Appendix E

Lake Marble Falls

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD | February 2020 Survey

CAPACITY IN ACRE-FEET | Conservation pool elevation 737.0 feet

ELEVATION INCREMENT IS ONE TENTH FOOT | Top of dam elevation 761.5 feet

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
679	0	0	0	0	0	0	0	0	0	0
680	0	0	0	0	0	0	0	0	0	0
681	0	0	1	1	1	1	1	1	1	1
682	1	1	1	2	2	2	2	2	2	2
683	3	3	3	3	3	3	4	4	4	4
684	4	5	5	5	5	5	6	6	6	7
685	7	7	7	8	8	8	9	9	9	9
686	10	10	10	11	11	11	12	12	13	13
687	13	14	14	15	15	15	16	16	17	17
688	18	18	19	19	20	20	21	21	22	23
689	23	24	24	25	26	26	27	28	28	29
690	30	31	31	32	33	34	35	36	36	37
691	38	39	40	41	42	43	44	45	47	48
692	49	50	51	53	54	55	57	58	59	61
693	62	64	65	66	68	70	71	73	74	76
694	78	79	81	83	85	86	88	90	92	94
695	96	98	100	102	104	107	109	111	113	115
696	118	120	122	125	127	129	132	134	137	139
697	142	144	147	149	152	154	157	160	163	165
698	168	171	174	177	180	183	185	188	191	195
699	198	201	204	207	210	213	217	220	223	227
700	230	233	237	240	244	247	251	254	258	262
701	265	269	273	277	280	284	288	292	296	300
702	304	308	312	316	320	324	329	333	337	341
703	346	350	355	359	364	368	373	378	382	387
704	392	397	402	407	412	417	422	427	432	437
705	443	448	453	459	464	470	475	481	487	492
706	498	504	510	516	522	528	534	541	547	553
707	559	566	572	578	585	591	598	605	611	618
708	625	632	638	645	652	659	666	673	681	688
709	695	702	710	717	725	732	740	748	756	763
710	771	779	787	795	804	812	820	828	837	845
711	853	862	870	879	888	896	905	914	923	932
712	941	950	959	968	977	986	996	1,005	1,014	1,024
713	1,033	1,043	1,052	1,062	1,072	1,081	1,091	1,101	1,111	1,121
714	1,131	1,141	1,151	1,161	1,171	1,181	1,191	1,202	1,212	1,222
715	1,233	1,243	1,254	1,264	1,275	1,285	1,296	1,307	1,317	1,328
716	1,339	1,350	1,361	1,372	1,383	1,394	1,405	1,416	1,428	1,439
717	1,450	1,462	1,473	1,484	1,496	1,508	1,519	1,531	1,543	1,555
718	1,567	1,579	1,591	1,603	1,615	1,627	1,640	1,652	1,665	1,677
719	1,690	1,703	1,716	1,729	1,743	1,756	1,770	1,783	1,797	1,811
720	1,825	1,839	1,854	1,868	1,883	1,898	1,913	1,928	1,943	1,958
721	1,974	1,989	2,005	2,021	2,037	2,053	2,069	2,086	2,103	2,119
722	2,136	2,153	2,171	2,188	2,205	2,223	2,241	2,258	2,276	2,294
723	2,312	2,331	2,349	2,367	2,386	2,405	2,423	2,442	2,461	2,480
724	2,500	2,519	2,538	2,558	2,578	2,598	2,618	2,638	2,658	2,679
725	2,699	2,720	2,741	2,762	2,783	2,805	2,826	2,848	2,870	2,892
726	2,915	2,937	2,960	2,983	3,006	3,029	3,053	3,076	3,100	3,124
727	3,149	3,173	3,198	3,223	3,249	3,275	3,300	3,327	3,353	3,380
728	3,407	3,434	3,462	3,490	3,518	3,547	3,576	3,606	3,635	3,666
729	3,696	3,727	3,759	3,790	3,823	3,856	3,889	3,923	3,957	3,992
730	4,028	4,064	4,101	4,138	4,176	4,214	4,253	4,292	4,332	4,372
731	4,413	4,455	4,497	4,540	4,583	4,626	4,670	4,715	4,759	4,805
732	4,850	4,896	4,943	4,990	5,037	5,085	5,133	5,181	5,230	5,279
733	5,329	5,379	5,430	5,481	5,532	5,584	5,636	5,689	5,742	5,796
734	5,851	5,905	5,960	6,016	6,071	6,127	6,183	6,240	6,297	6,353
735	6,411	6,468	6,526	6,583	6,641	6,700	6,758	6,817	6,876	6,935
736	6,994	7,053	7,113	7,173	7,233	7,293	7,354	7,414	7,475	7,536
737	7,597	7,659	7,721	7,782	7,844	7,907	7,969	8,032	8,095	8,158
738	8,221	8,285	8,349	8,413	8,477	8,542	8,606	8,671	8,736	8,801

Appendix E (continued)

Lake Marble Falls

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — February 2020 Survey

CAPACITY IN ACRE-FEET — Conservation pool elevation 737.0 feet

ELEVATION INCREMENT IS ONE TENTH FOOT — Top of dam elevation 761.5 feet

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
739	8,866	8,931	8,996	9,062	9,127	9,193	9,259	9,325	9,391	9,457
740	9,524	9,591	9,658	9,725	9,792	9,859	9,927	9,994	10,062	10,130
741	10,199	10,267	10,335	10,404	10,473	10,542	10,611	10,681	10,750	10,820
742	10,890	10,960	11,031	11,101	11,172	11,243	11,315	11,386	11,458	11,530
743	11,602	11,675	11,747	11,820	11,893	11,967	12,040	12,114	12,188	12,262
744	12,336	12,410	12,485	12,560	12,634	12,709	12,785	12,860	12,936	13,012
745	13,088	13,164	13,240	13,317	13,393	13,470	13,547	13,625	13,702	13,780
746	13,858	13,936	14,014	14,093	14,171	14,250	14,330	14,409	14,488	14,568
747	14,648	14,728	14,809	14,889	14,970	15,051	15,133	15,214	15,296	15,378
748	15,460	15,542	15,625	15,707	15,790	15,873	15,957	16,040	16,124	16,208
749	16,292	16,376	16,460	16,545	16,630	16,714	16,800	16,885	16,971	17,056
750	17,142	17,228	17,315	17,401	17,488	17,575	17,662	17,750	17,837	17,925
751	18,013	18,102	18,190	18,279	18,368	18,457	18,547	18,636	18,726	18,817
752	18,907	18,998	19,089	19,181	19,272	19,364	19,457	19,549	19,642	19,735
753	19,829	19,923	20,017	20,112	20,207	20,302	20,397	20,493	20,590	20,686
754	20,783	20,880	20,978	21,076	21,174	21,273	21,372	21,472	21,571	21,672
755	21,772	21,873	21,974	22,076	22,178	22,280	22,383	22,486	22,589	22,693
756	22,797	22,902	23,006	23,112	23,217	23,324	23,430	23,537	23,644	23,751
757	23,859	23,967	24,076	24,185	24,295	24,404	24,515	24,625	24,736	24,848
758	24,960	25,073	25,186	25,299	25,414	25,528	25,644	25,759	25,875	25,992
759	26,109	26,227	26,345	26,463	26,582	26,702	26,822	26,942	27,063	27,185
760	27,307	27,429	27,553	27,677	27,801	27,926	28,052	28,179	28,306	28,435
761	28,564	28,693	28,824	28,955	29,087	29,219				

Appendix F

Lake Marble Falls

RESERVOIR BATHYMETRIC AND TOPOGRAPHIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — February 2020 Survey

AREA IN ACRES — Conservation pool elevation 737.0 feet

ELEVATION INCREMENT IS ONE TENTH FOOT — Top of dam elevation 761.5 feet

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
679	0	0	0	0	0	0	0	0	0	0
680	0	0	0	0	0	0	0	1	1	1
681	1	1	1	1	1	1	1	1	1	1
682	1	1	1	1	1	1	1	1	1	2
683	2	2	2	2	2	2	2	2	2	2
684	2	2	2	2	2	3	3	3	3	3
685	3	3	3	3	3	3	3	3	3	3
686	3	3	3	3	3	4	4	4	4	4
687	4	4	4	4	4	4	4	5	5	5
688	5	5	5	5	5	5	6	6	6	6
689	6	6	6	6	7	7	7	7	7	7
690	8	8	8	8	8	8	9	9	9	9
691	9	10	10	10	10	11	11	11	11	12
692	12	12	12	13	13	13	13	14	14	14
693	14	15	15	15	15	16	16	16	16	17
694	17	17	17	18	18	18	19	19	19	20
695	20	20	21	21	21	22	22	22	22	23
696	23	23	23	23	24	24	24	24	25	25
697	25	25	26	26	26	27	27	27	27	28
698	28	28	29	29	29	30	30	30	30	31
699	31	31	32	32	32	32	33	33	33	34
700	34	34	34	35	35	35	36	36	36	37
701	37	37	37	38	38	38	39	39	39	40
702	40	41	41	41	42	42	42	43	43	44
703	44	45	45	45	46	46	47	47	47	48
704	48	49	49	50	50	50	51	51	52	53
705	53	54	54	55	55	56	56	57	57	58
706	59	59	60	60	61	61	61	62	62	63
707	63	64	64	65	65	65	66	66	67	67
708	68	68	69	69	70	70	71	71	72	73
709	73	74	74	75	76	76	77	78	78	79
710	79	80	80	81	81	82	83	83	84	84
711	85	85	86	86	87	87	88	88	89	89
712	90	90	91	92	92	93	93	94	94	94
713	95	96	96	97	97	97	98	98	99	99
714	100	100	101	101	102	102	102	103	103	104
715	104	105	105	106	106	106	107	107	108	108
716	109	109	110	110	111	111	112	112	112	113
717	113	114	115	115	116	116	117	118	118	119
718	120	120	121	122	123	124	124	125	126	127
719	129	130	131	132	133	135	136	137	139	140
720	141	143	144	146	147	149	150	151	153	154
721	155	157	158	160	161	163	164	166	167	168
722	170	171	172	174	175	176	177	178	180	181
723	182	183	184	185	186	187	188	189	191	192
724	193	194	195	197	198	200	201	202	204	206
725	207	209	210	212	213	215	217	219	220	222
726	224	226	228	230	232	234	236	238	240	243
727	245	248	251	253	255	258	261	263	266	269
728	272	275	278	282	285	289	292	296	300	304
729	308	312	316	321	325	331	336	342	348	354
730	360	365	370	375	380	385	390	396	401	407
731	413	419	424	428	433	437	441	446	450	454
732	459	463	467	471	475	479	483	487	491	495
733	499	504	508	512	515	519	525	532	537	541
734	545	548	552	555	558	561	563	566	568	571
735	573	575	577	579	581	583	585	587	589	591
736	593	595	598	600	602	604	606	608	610	612
737	614	615	617	620	622	624	626	628	630	632
738	635	639	640	641	643	644	646	647	648	650

Appendix F (continued)

Lake Marble Falls

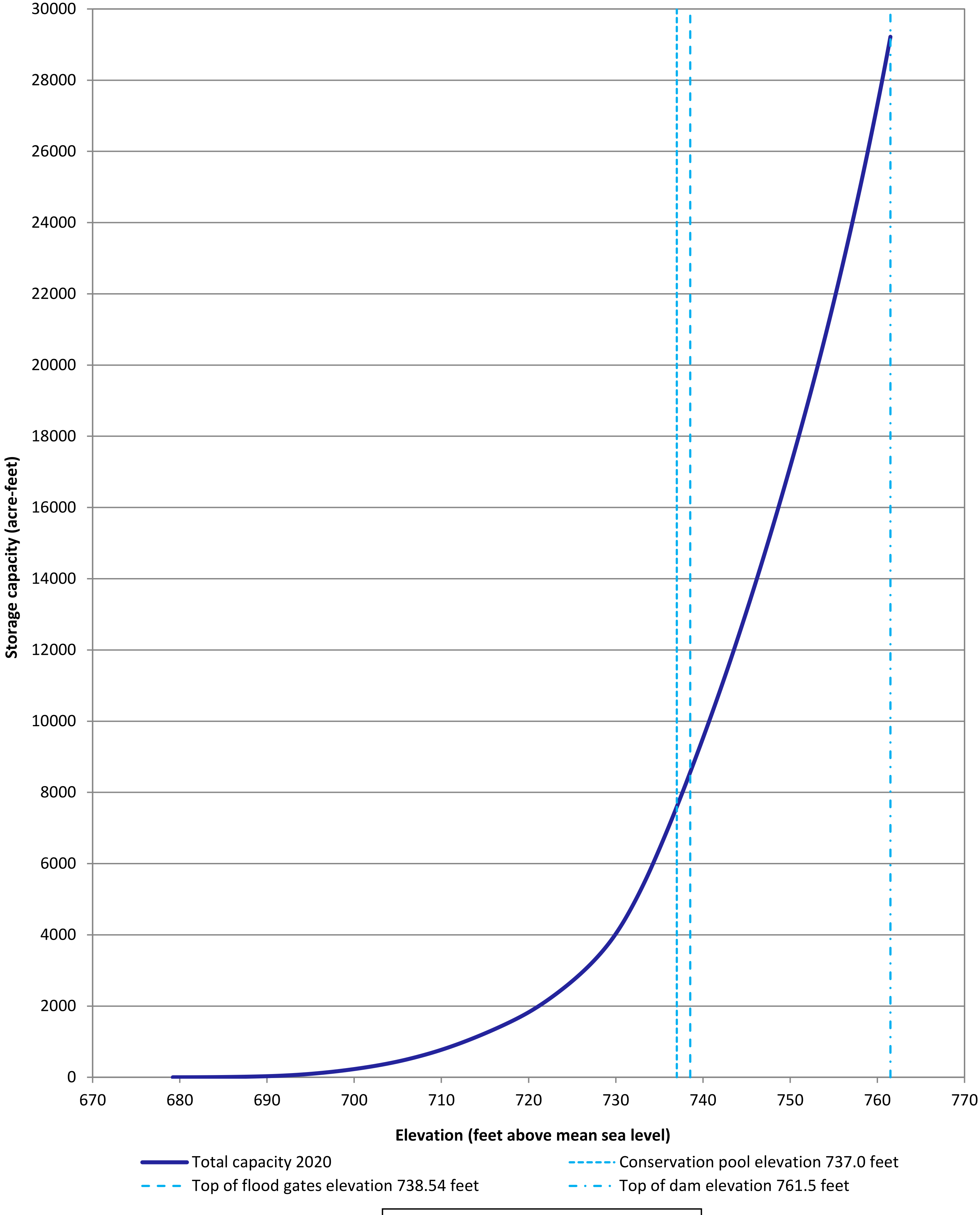
RESERVOIR BATHYMETRIC AND TOPOGRAPHIC AREA TABLE

TEXAS WATER DEVELOPMENT BOARD | February 2020 Survey

AREA IN ACRES | Conservation pool elevation 737.0 feet

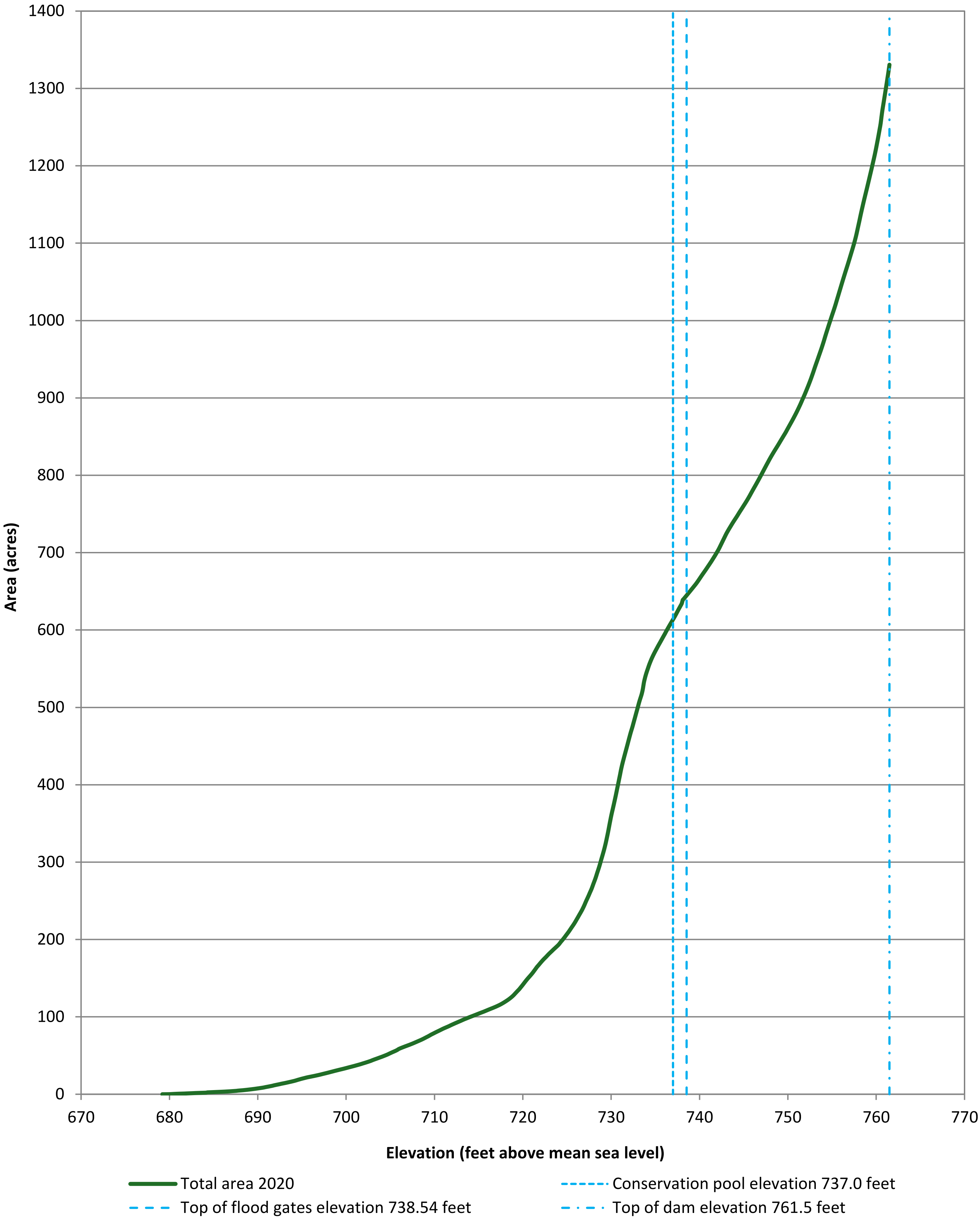
ELEVATION INCREMENT IS ONE TENTH FOOT | Top of dam elevation 761.5 feet

ELEVATION (Feet MSL)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
739	651	653	654	655	657	658	660	661	663	665
740	666	668	670	671	673	675	676	678	679	681
741	683	685	686	688	690	692	693	695	697	699
742	701	703	705	707	710	712	714	717	719	721
743	724	726	728	730	732	734	736	737	739	741
744	743	745	746	748	750	752	754	755	757	759
745	761	763	764	766	768	770	772	774	776	778
746	780	782	784	786	788	790	792	794	797	799
747	801	803	805	807	809	812	814	816	818	820
748	822	824	826	828	830	832	834	836	837	839
749	841	843	845	847	849	851	853	854	856	859
750	861	863	865	867	869	871	873	875	877	880
751	882	884	887	889	891	894	897	899	902	904
752	907	910	913	915	918	921	924	928	931	934
753	938	941	944	947	951	954	957	961	964	967
754	971	975	978	982	986	989	993	996	1,000	1,003
755	1,007	1,010	1,014	1,017	1,021	1,025	1,028	1,032	1,036	1,040
756	1,044	1,048	1,051	1,055	1,059	1,062	1,066	1,070	1,073	1,077
757	1,081	1,084	1,088	1,092	1,096	1,100	1,104	1,108	1,113	1,119
758	1,124	1,129	1,134	1,140	1,145	1,150	1,155	1,159	1,164	1,169
759	1,173	1,178	1,183	1,188	1,193	1,197	1,202	1,207	1,212	1,218
760	1,223	1,229	1,235	1,242	1,248	1,254	1,263	1,272	1,279	1,286
761	1,293	1,300	1,308	1,315	1,323	1,331				



Lake Marble Falls
February 2020 Survey
Prepared by: TWDB

Appendix G: Bathymetric and topographic capacity curve



Lake Marble Falls
February 2020 Survey
Prepared by: TWDB

Appendix H: Bathymetric and topographic area curve

Appendix I

Lake Marble Falls

Axial profile map

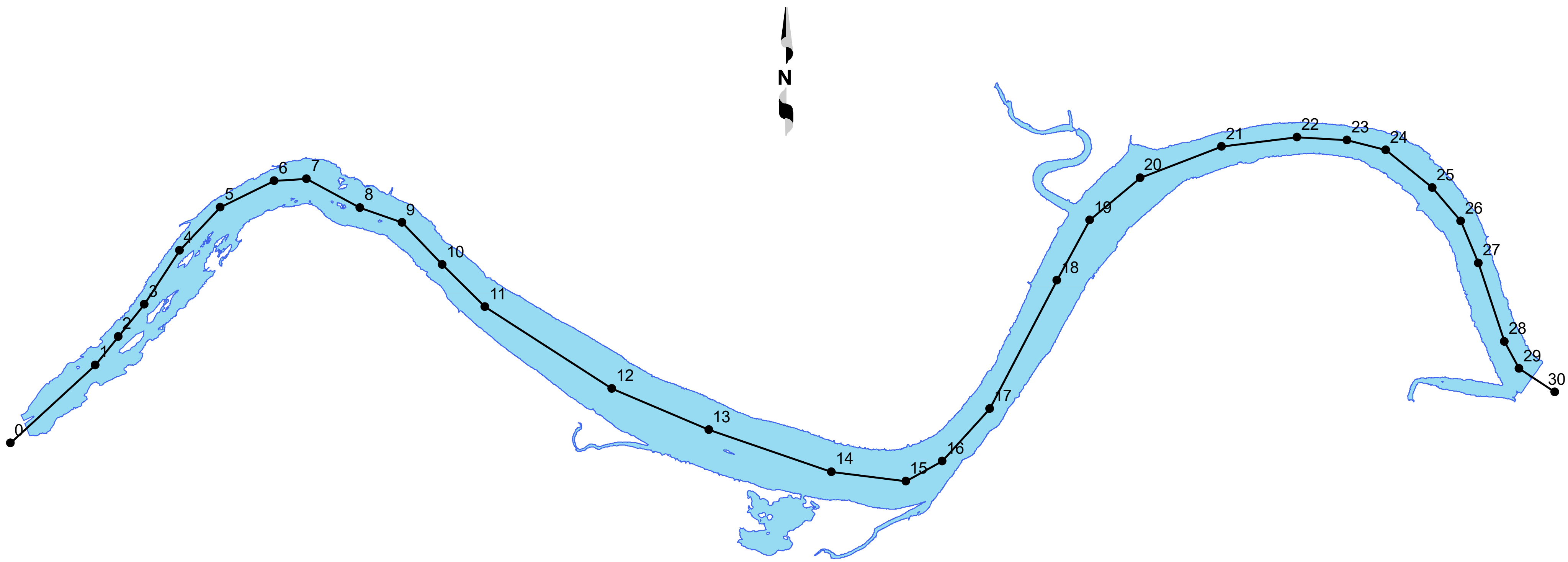


Table I1. Lake Marble Falls axial profile vertice coordinates

Point ID	x	y	Point ID	x	y
0	2,924,357.82	10,171,233.75	16	2,940,205.00	10,170,927.94
1	2,925,797.75	10,172,565.69	17	2,941,010.73	10,171,821.10
2	2,926,191.24	10,173,048.97	18	2,942,152.51	10,174,001.96
3	2,926,635.77	10,173,598.78	19	2,942,713.31	10,175,025.04
4	2,927,232.89	10,174,514.72	20	2,943,567.33	10,175,748.38
5	2,927,931.03	10,175,247.44	21	2,944,954.27	10,176,278.72
6	2,928,846.44	10,175,692.63	22	2,946,239.62	10,176,438.54
7	2,929,395.38	10,175,731.55	23	2,947,091.75	10,176,390.95
8	2,930,305.89	10,175,240.52	24	2,947,745.33	10,176,217.37
9	2,931,016.05	10,174,986.27	25	2,948,540.60	10,175,580.38
10	2,931,702.67	10,174,268.40	26	2,949,019.49	10,175,013.01
11	2,932,427.59	10,173,551.88	27	2,949,325.50	10,174,297.74
12	2,934,589.48	10,172,163.89	28	2,949,762.33	10,172,964.19
13	2,936,233.00	10,171,459.21	29	2,950,013.70	10,172,503.00
14	2,938,319.25	10,170,747.03	30	2,950,625.85	10,172,103.90
15	2,939,583.65	10,170,588.81			

XY coordinates in NAD83 State Plane Texas Central Zone (feet)

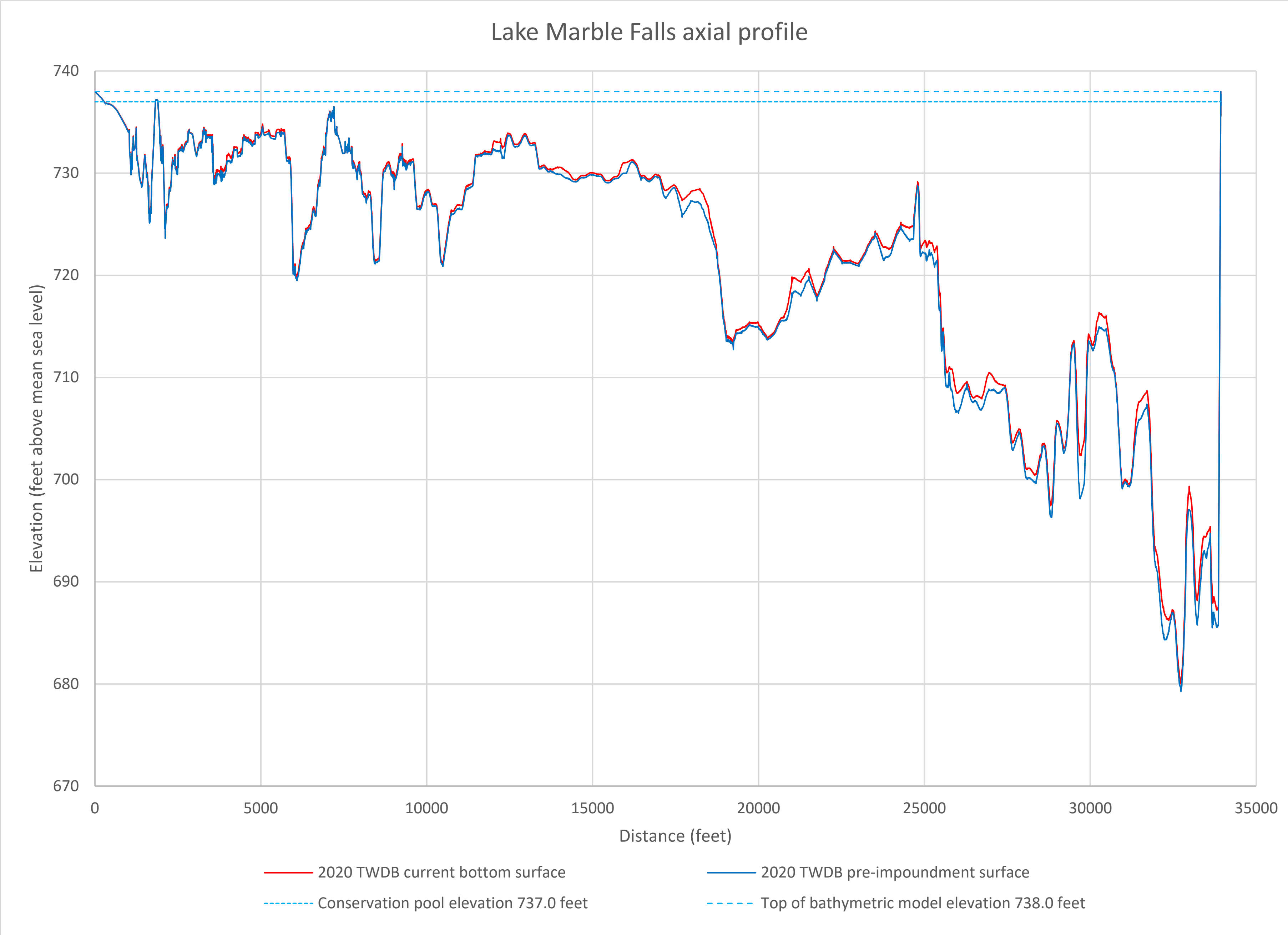
Axial profile

Lake Marble Falls elevation 738.0 feet
Conservation pool elevation 737.0 feet

Projection: NAD83 State Plane
Texas Central Zone (feet)

Miles
0 0.25 0.5 1

Texas Water Development Board
February 2020 Survey



Lake Marble Falls axial profile
Elevation (feet above mean sea level)
740
730
720
710
700
690
680
670
0
5000
10000
15000
20000
25000
30000
35000
Distance (feet)
2020 TWDB current bottom surface
2020 TWDB pre-impoundment surface
Conservation pool elevation 737.0 feet
Top of bathymetric model elevation 738.0 feet

Figure 6

CONTOURS
(feet above mean sea level)

737
735
730
725
720
715
710
705
700
695
690
685
680

Islands

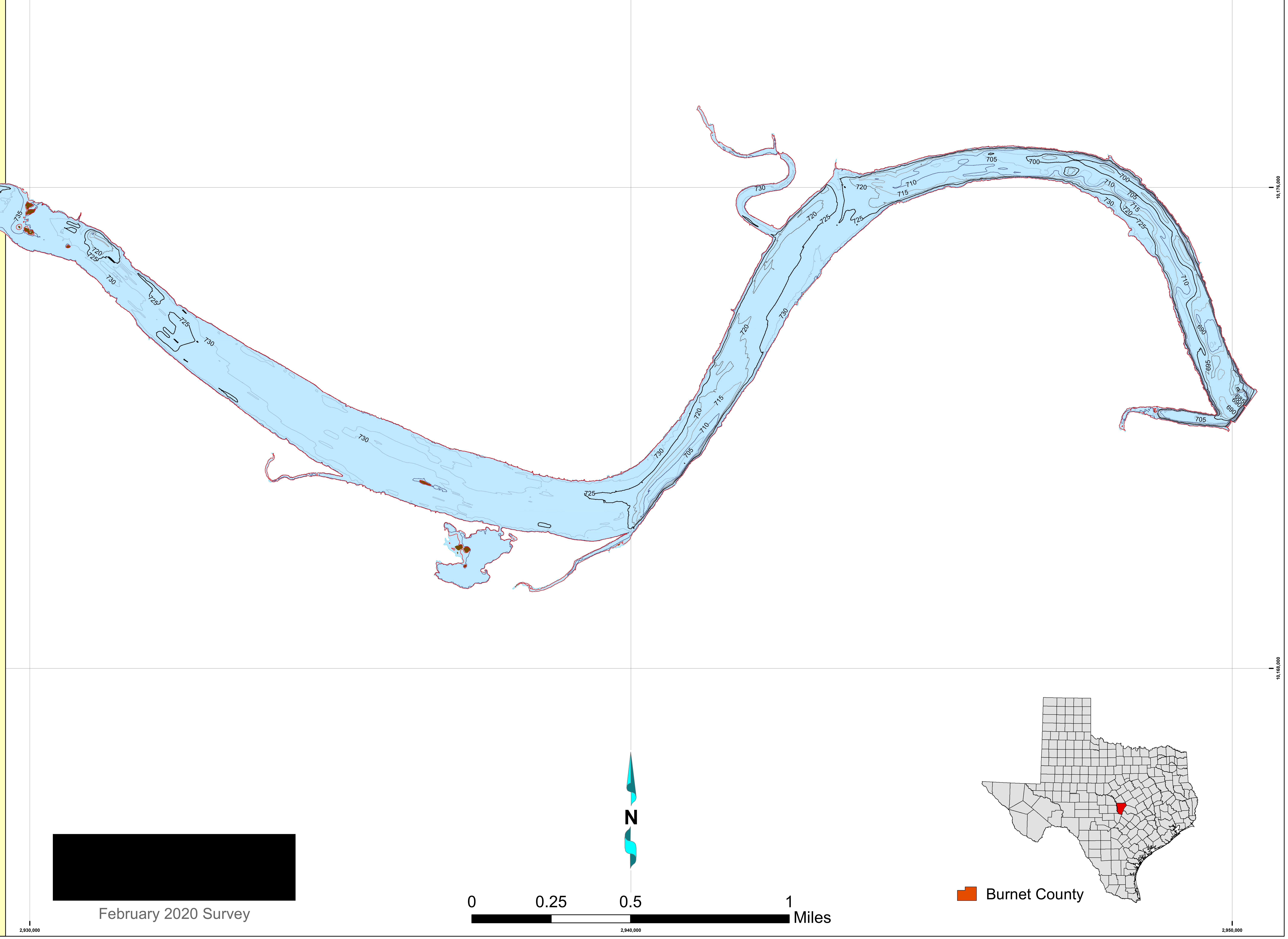
Lake Marble Falls
Elevation 738.0 feet
Conservation pool
elevation 737.0 feet

Projection: NAD83 State Plane
Texas Central Zone (feet)

This map is the product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Lake Marble Falls. The Texas Water Development Board makes no representations nor assumes any liability.

Lake Marble Falls

5' - contour map



[redacted]

February 2020 Survey